S
363.7394
E30WQR
2006 V. 2 BK. 2
1

2006

Montana State Library
3 0864 1003 9974 3

ework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report, Book 2 of 2

Appendix C through Appendix K

Montana Department of
Environmental Quality

Digitized by the Internet Archive
in 2011 with funding from
Montana State Library

http://www.archive.org/details/frameworkwat200622mont

Appendix C

GWLF/BATHTUB Modeling

Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report

August 31, 2006

Prepared for the Montana Department of Environmental Quality

Prepared by the U.S. Environmental Protection Agency,
Montana Operations Office
With Technical Support from Tetra Tech, Inc.
and PBS&J, Inc.

Project Manager: Ron Steg

Contents

1.0 INTRODUCTION 1
2.0 GWLF MODEL DEVELOPMENT 5
  2.1 Transport Data 5
    2.1.1 Subwatershed Delineation 6
    2.1.2 Land Use in the Lake Helena Watershed 8
    2.1.3 USLE Parameters 14
    2.1.4 Soil Water Capacity and River Recession 18
  2.2 Weather Data 18
  2.3 Nutrient Data 19
    2.3.1 Soil Nutrient Concentrations 19
    2.3.2 Runoff Concentrations from Rural Land Uses 20
    2.3.3 Buildup Washoff Rates from Urban Land Uses 21
    2.3.4 Groundwater Nutrient Concentrations 21
    2.3.5 Septic System Loading Data 22
    2.3.6 Point Sources 27
  2.4 Additional Considerations 29
    2.4.1 Streambank Erosion 29
    2.4.2 Upper Tenmile Creek Diversions 31
    2.4.3 Abandoned Mines 31
    2.4.4 Loads from the Helena Valley Irrigation District 35
    2.4.5 City of Helena Stormwater System 36
    2.4.6 Sewer System Expansion – Hypothetical Scenario 37
  2.5 Summary of Pollutant Loading Sources 40
  2.6 GWLF Calibration 45
    2.6.1 Hydrologic Calibration 45
    2.6.2 Nutrient Calibration 49
3.0 BATHTUB MODEL SETUP 53
  3.1 Lake Morphology 53
  3.2 Atmospheric Deposition to Lake Helena 53
  3.3 Inorganic Nutrient Fractions 53
  3.4 Light Penetration in Lake Helena 54
  3.5 BATHTUB Calibration 54
4.0 APPLICATION OF THE GWLF/BATHTUB MODELS 57
  4.1 Required Nutrient Reductions for Each TMDL Watershed 57
    4.1.1 Prickly Pear Creek 57
    4.1.2 Tenmile Creek 59
    4.1.3 Sevenmile Creek 61
    4.1.4 Spring Creek 62
  4.2 Natural Scenario 64
  4.3 Reduced Scenario 68
  4.4 Simplistic Build-out Scenario 69
  4.5 Lake Helena Response to Scenarios 73
5.0 UNCERTAINTY OF THE GWLF/BATHTUB MODELING 75
6.0 REFERENCES 77

Tables

Table 1. Listed Reaches in the Lake Helena Watershed 3
Table 2. Drainage Area and Mean Elevation of the Lake Helena Subwatersheds 8
Table 3. Land Use Areas for the Lake Helena Existing Conditions Modeling 10
Table 4. Harvest Data by Agency in the Lake Helena Watershed for the period 1996 to 2000. 13
Table 5. SCS Curve Numbers for Land Uses in the Lake Helena Watershed 14
Table 6. Average Land Slopes, Soil Erodibility Factors, and Length-Slope Factors by Subwatershed 16
Table 7. Cover Factors by Land Use in the Lake Helena Watershed 17
Table 8. Sediment Delivery Ratios for the Lake Helena Subwatersheds 18
Table 9. Nutrient Runoff Concentrations for Rural Land Uses in the Lake Helena Watershed 20
Table 10. Buildup Washoff Rates for Urban Land Uses in the Lake Helena Watershed 21
Table 11. Estimated Groundwater Nutrient Concentrations for the Lake Helena Subwatersheds Under Existing Conditions 22
Table 12. Population Served by Septic Systems in the Lake Helena Watershed 24
Table 13. Septic System Loading Rates and Plant Uptake Rates 25
Table 14. Comparison of Loading Rates from Septic Systems in the Lake Helena Watershed Under Four Failure Scenarios 26
Table 15. Typical Nutrient Concentrations Reported in USEPA, 1997 27
Table 16. Average Flow Rates and Annual Nutrient Loads from Centralized Wastewater Treatment Systems in the Lake Helena Watershed 27
Table 17. Bank Retreat Rates Used for Banks of Varying Severity of Erosion 30
Table 18. Sediment Loads from Eroding Streambanks by Source 31
Table 19. Sediment Loads from Abandoned Mine Sites 34
Table 20. Sediment Loads from Abandoned Mine Sites by Sub-Watershed 35
Table 21. Sediment and Nutrient Loads from Abandoned Mines in the Lake Helena Watershed 35
Table 22. Water Balance for the Helena Valley Irrigation District for 2003 36
Table 23. Additional Flow Volumes and Loads from the Helena Valley Irrigation District 36
Table 24. Comparison of Cumulative Nitrogen Loading Under Two Hypothetical Annexation Scenarios 39
Table 25. Comparison of Cumulative Phosphorus Loading Under Two Hypothetical Annexation Scenarios 40
Table 26. Summary of Pollutant Loading Sources in the Lake Helena Watershed 41
Table 27. Observations of Stream Flow, Total Phosphorus, and Total Nitrogen at USGS Gage 06063000 on Tenmile Creek 49
Table 28. Observations of Stream Flow, Total Phosphorus, and Total Nitrogen at USGS Gage 06061500 on Prickly Pear Creek 51
Table 29. Lake Helena Morphology 53
Table 30. Inorganic Nutrient Fractions to Lake Helena 54
Table 31. Comparison of Observed and Simulated Total Nitrogen Concentrations (mg-N/L) in Lake Helena 55
Table 32. Comparison of Observed and Simulated Total Phosphorus Concentrations (mg-P/L) in Lake Helena 55
Table 33. Comparison of Observed and Simulated Chlorophyll *a* Concentrations (μg-N/L) in Lake Helena 56
Table 34. Observed Nutrient Data in Prickly Pear Creek Segment MT41I006_020 58
Table 35. Comparison of Annual and Average Annual Nutrient Load Reductions 58
Table 36. Observed Nutrient Data in Tenmile Creek Segment MT41I006_143 60
Table 37. Observed Nutrient Data in Sevenmile Creek Segment MT41I006_160 61
Table 38. Observed Nutrient Data in Spring Creek Segment MT41I006_080 62
Table 39. Cumulative Nutrient Load Reductions for Listed Segments in the Lake Helena Watershed as Determined Using Observed Concentrations and Simulated Loads (Proposed Load Reductions Shown in Bold) 63
Table 40. Land Use Areas for the Lake Helena Existing and Natural Conditions Modeling 64
Table 41. Change in Annual Sediment Load from Existing to Natural Conditions in Lake Helena Modeling Subwatersheds 65

Table 42. Change in Annual Nitrogen Load from Existing to Natural Conditions in Lake Helena Modeling Subwatersheds 66
Table 43. Change in Annual Phosphorus Load from Existing to Natural Conditions in Lake Helena Modeling Subwatersheds 67
Table 44. Change in Annual Sediment Load from Existing to Buildout Conditions in Lake Helena Modeling Subwatersheds 70
Table 45. Change in Annual Nitrogen Load from Existing to Buildout Conditions in Lake Helena Modeling Subwatersheds 71
Table 46. Change in Annual Phosphorus Load from Existing to Buildout Conditions in Lake Helena Modeling Subwatersheds 72
Table 47. Comparison of Simulated Average Total Nitrogen, Total Phosphorus, and Chlorophyll a Concentrations in Lake Helena Under Four Modeling Scenarios 73

Figures

Figure 1. 303(d) Listed Segments in the Lake Helena Watershed 2
Figure 2. Lake Helena DEM, NHD Stream Coverage, and Subwatersheds 7
Figure 3. Land Use in the Lake Helena Watershed (Area Highlighted in Red was Updated Based on 2004 Aerial Photography) 9
Figure 4. Land Ownership in the Lake Helena Watershed 12
Figure 5. STATSGO Soil Types in the Lake Helena Watershed 15
Figure 6. Comparison of Observed and Estimated Precipitation at the Frohner SNOTEL Station 19
Figure 7. Permitted Septic Systems in Lewis & Clark County and Wells Coverage for the Watershed 23
Figure 8. Location of Centralized Wastewater Facilities in the Lake Helena Watershed 28
Figure 9. Location of Sediment-Producing Abandoned Mines in the Lake Helena Watershed 33
Figure 10. Sewer Service and Hypothetical Sewer System Expansion Zones in the Lake Helena Watershed 38
Figure 11. Average Annual Flows Over the Period of Record for Prickly Pear Creek Near Clancy (USGS Gage 06061500) 45
Figure 12. Comparison of Simulated and Observed Monthly Flow Volumes at USGS Gage 06061500, Along with Monthly Precipitation at the Helena Airport 46
Figure 13. Comparison of Simulated and Observed Monthly Flow Volumes at USGS Gage 06061500 for the Period January 1, 1998 through December 31, 2000 47
Figure 14. Range of Simulated and Observed Monthly Flows at USGS Gage 06061500 for the period 1980 to 2002 47
Figure 15. Comparison of Simulated and Observed Annual Flow Volumes at USGS Gage 06061500 for the Period 1980 to 2002 48
Figure 16. Comparison of Observed and Simulated Daily Total Nitrogen Load at USGS Gage 06063000 Along Tenmile Creek (Observed Loads Based on 8 Samples; Simulated Loads Based on Twenty Years of Model Output) 50
Figure 17. Comparison of Observed and Simulated Daily Total Phosphorus Load at USGS Gage 06063000 Along Tenmile Creek (Observed Loads Based on 8 Samples; Simulated Loads Based on Twenty Years of Model Output) 50
Figure 18. Comparison of Observed and Simulated Daily Total Nitrogen Load at USGS Gage 06061500 Along Prickly Pear Creek (Observed Loads Based on 20 Samples; Simulated Loads Based on Twenty Years of Model Output) 52
Figure 19. Comparison of Observed and Simulated Daily Total Phosphorus Load at USGS Gage 06061500 Along Prickly Pear Creek (Observed Loads Based on 20 Samples; Simulated Loads Based on Twenty Years of Model Output) 52

1.0 INTRODUCTION

The Lake Helena Volume I report concluded that twenty stream reaches in the Lake Helena Watershed are impaired for sediment and/or nutrients (Figure 1, Table 1). To better understand the impairments, sediment and nutrients were modeled with the Generalized Watershed Loading Functions (GWLF) model (Haith et al., 1992). The primary purpose of the modeling effort was to determine the sediment and nutrient loads from each significant source category (e.g., point sources, roads, septic systems). The model was secondarily used to help answer the following questions:

- What is the extent to which sediment and nutrient loads in the watershed have been affected by anthropogenic activities (i.e., comparison of existing and natural scenarios)?
- How might loads change in the future with increased development of the watershed (i.e., comparison of existing and build out scenarios)?
- What are the allowable loads at various ungaged points in the watershed?

GWLF simulates runoff and stream flow by a water-balance method, based on measurements of daily precipitation and average temperature. The complexity of GWLF falls between that of detailed, process-based simulation models and simple export coefficient models which do not represent temporal variability. The application of a more detailed model was not warranted given the general lack of water quality data with which it could be calibrated (refer to Volume I). The GWLF model was determined to be appropriate because it simulates the important processes of concern, but does not require as much data for calibration. Loads from several sources (point sources, Helena Valley Irrigation District, abandoned mines, streambank erosion) were estimated separately and added to the GWLF output during post processing.

GWLF input parameters were assigned based on available monitoring data, default parameters suggested in the GWLF User's Manual (Haith et al., 1992), and local resource agency recommendations. Default values were used for many parameters due to a lack of local data and to ensure the modeling results are consistent with previously validated studies.

The U.S. Army Corps of Engineers' BATHTUB model was selected to simulate eutrophication in Lake Helena. BATHTUB predicts eutrophication-related water quality conditions (e.g., phosphorus, nitrogen, chlorophyll *a*, and transparency) using empirical relationships previously developed and tested for reservoir applications (Walker, 1987). Similar to GWLF, BATHTUB was chosen based on the lack of historic water quality data with which to calibrate a more detailed model. Simulated watershed loads from GWLF were used to drive the BATHTUB model to answer the following questions:

- What is the extent to which sediment and nutrient loads in the watershed have been affected by anthropogenic activities (i.e., comparison of existing and natural scenarios)?
- How might loads change in the future with increased development of the watershed (i.e., comparison of existing and build out scenarios)?

The following sections discuss the setup, calibration, and use of the GWLF and BATHTUB models.

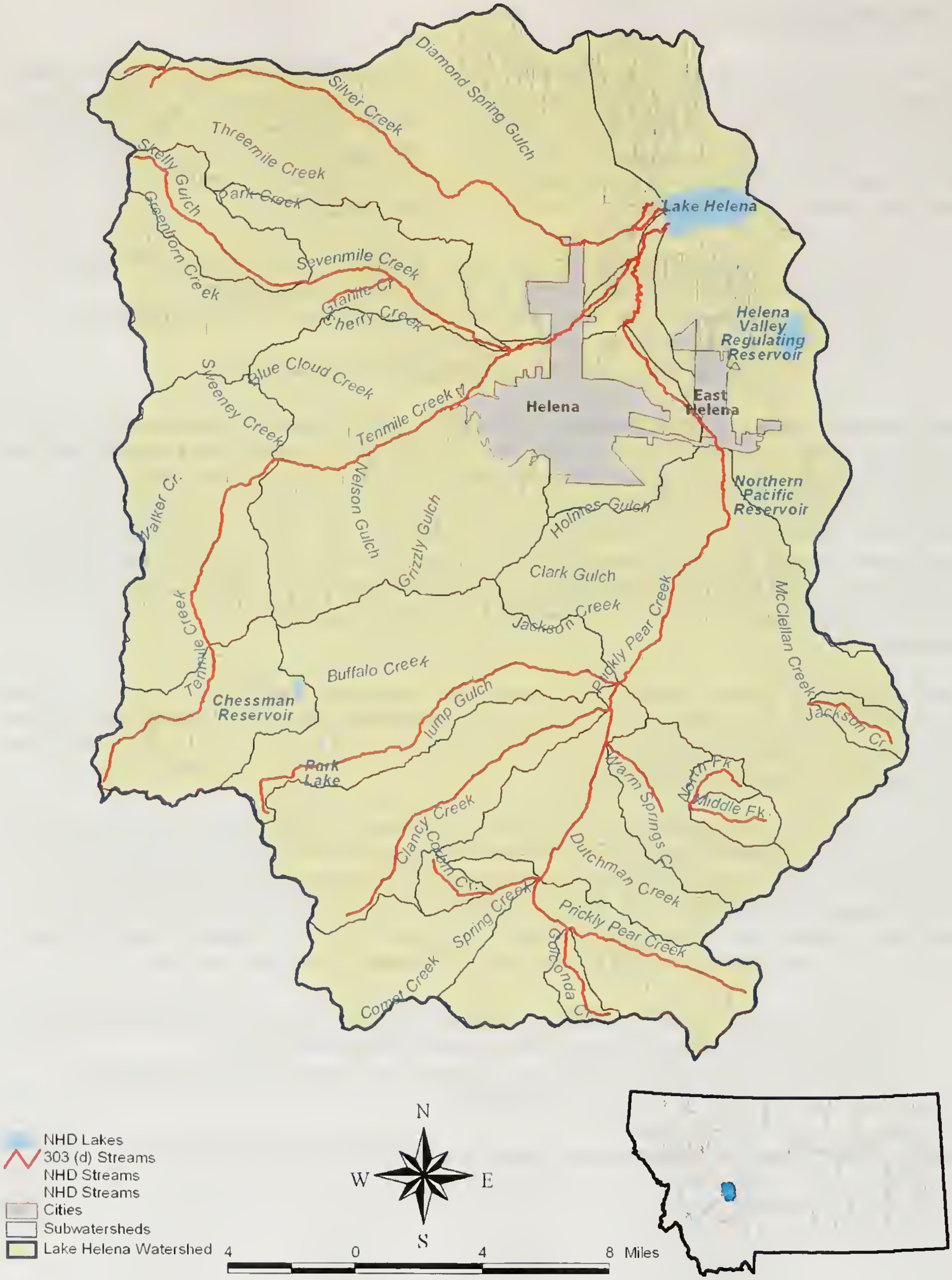


Figure 1. 303(d) Listed Segments in the Lake Helena Watershed

Table 1. Listed Reaches in the Lake Helena Watershed

WBKEY	Reach Description	Length (mile)	Impairment
MT41I006_180	North Fork Warm Springs Creek, Headwaters to mouth	2.50	Sediment
MT41I006_210	Jennies Fork from headwaters to mouth	1.41	Sediment
MT41I006_070	Golconda Creek, Headwaters to the mouth	3.71	Sediment
MT41I006_060	Prickly Pear Creek from headwaters to Spring Cr	8.65	Sediment
MT41I006_080	Spring Creek from Corbin Cr to the mouth	1.66	Sediment, nutrients
MT41I006_090	Corbin Creek from headwaters to the mouth	2.52	Sediment
MT41I006_100	Middle Fork Warm Springs Creek, Headwaters to mouth	2.68	Sediment
MT41I006_050	Prickly Pear Creek from Spring Cr to Lump Gulch	7.01	Sediment
MT41I006_110	Warm Springs Creek from the Middle Fork to the mouth	2.96	Sediment
MT41I006_120	Clancy Creek from headwaters to the mouth	11.56	Sediment, nutrients
MT41I006_130	Lump Gulch from headwaters to the mouth	14.47	Sediment
MT41I006_141	Tenmile Creek, headwaters to the Helena PWS intake above Rimini	6.82	Sediment
MT41I006_040	Prickly Pear Creek from Lump Gulch to Montana Highway 433 Crossing	10.43	Sediment
MT41I006_142	Tenmile Creek From the Helena PWS intake above Rimini to the Helena WT plant.	7.30	Sediment
MT41I006_143	Tenmile Creek from the Helena WT plant to the mouth	15.45	Sediment, nutrients
MT41I006_160	Sevenmile Creek from headwaters to the mouth	7.76	Sediment, nutrients
MT41I006_020	Prickly Pear Creek from Helena WWTP Discharge Ditch to Lake Helena	5.92	Sediment, nutrients
MT41I006_220	Skelly Gulch tributary of Greenhorn Cr-Sevenmile Cr T10N R5W Sec 2	7.71	Sediment
MT41I006_030	Prickly Pear Creek from Highway 433 Crossing to Helena WWTP Discharge	4.42	Sediment, nutrients
MT41I006_190	Jackson Creek from headwaters to the mouth	3.24	Sediment

2.0 GWLF MODEL DEVELOPMENT

GWLF provides a mechanistic, but simplified, simulation of precipitation-driven runoff and sediment delivery. Solids load, runoff, and ground water seepage are used to estimate particulate and dissolved-phase pollutant delivery to a stream, based on pollutant concentrations in soil, runoff, and ground water. GWLF simulates runoff and stream flow by a water-balance method, based on measurements of daily precipitation and average temperature. Precipitation is partitioned into direct runoff and infiltration using a form of the Natural Resources Conservation Service's (NRCS) Curve Number method (SCS, 1986). The Curve Number determines the amount of precipitation that runs off directly, adjusted for antecedent soil moisture based on total precipitation in the preceding 5 days.

Flow in streams may derive from surface runoff during precipitation events or from ground water pathways. The amount of water available to the shallow ground water zone is strongly affected by evapotranspiration, which GWLF estimates from available moisture in the unsaturated zone, potential evapotranspiration, and a cover coefficient. Potential evapotranspiration is estimated from a relationship to mean daily temperature and the number of daylight hours.

The user of the GWLF model must divide land uses into "rural" and "urban" categories, which determines how the model calculates loading of sediment and nutrients. For the purposes of modeling, "rural" land uses are those with predominantly pervious surfaces, while "urban" land uses are those with predominantly impervious surfaces. Monthly sediment delivery from each "rural" land use is computed from erosion and the transport capacity of runoff, whereas total erosion is based on the universal soil loss equation (USLE) (Wischmeier and Smith, 1978), with a modified rainfall erosivity coefficient that accounts for the precipitation energy available to detach soil particles (Haith and Merrill, 1987). Thus, erosion can occur when there is precipitation, but no surface runoff to the stream; delivery of sediment, however, depends on surface runoff volume. Sediment available for delivery is accumulated over a year, although excess sediment supply is not assumed to carry over from one year to the next. Nutrient loads from rural land uses may be dissolved (in runoff) or solid-phase (attached to sediment loading as calculated by the USLE).

For "urban" land uses, soil erosion is not calculated, and delivery of nutrients to the water bodies is based on an exponential accumulation and washoff formulation. All nutrients loaded from urban land uses are assumed to move in association with solids.

GWLF requires three input files to simulate runoff and pollutant loads from each subwatershed. The weather file contains daily values of precipitation and average temperature. The nutrient file contains nitrogen and phosphorus concentrations of groundwater and runoff as well as build-up wash off rates from urban areas. The transport file contains land use areas and parameters for estimating runoff, erosion, and evapotranspiration. This section of the report describes the modeling assumptions used to develop these three files for existing and natural conditions.

2.1 Transport Data

Land use areas, soil erodibility factors, and evapotranspiration rates were developed based on MRLC, STATSGO, and Agri-met datasets, respectively, and are described more fully below.

2.1.1 Subwatershed Delineation

The first step in developing the transport files was to delineate subwatersheds corresponding to the listed segments and major stream confluences. The Lake Helena Watershed was delineated into twenty-two subwatersheds based on a 30-meter digital elevation model of the watershed and the National Hydrography Dataset stream coverage as shown in Figure 2. Watershed area and mean elevation are listed in Table 2.

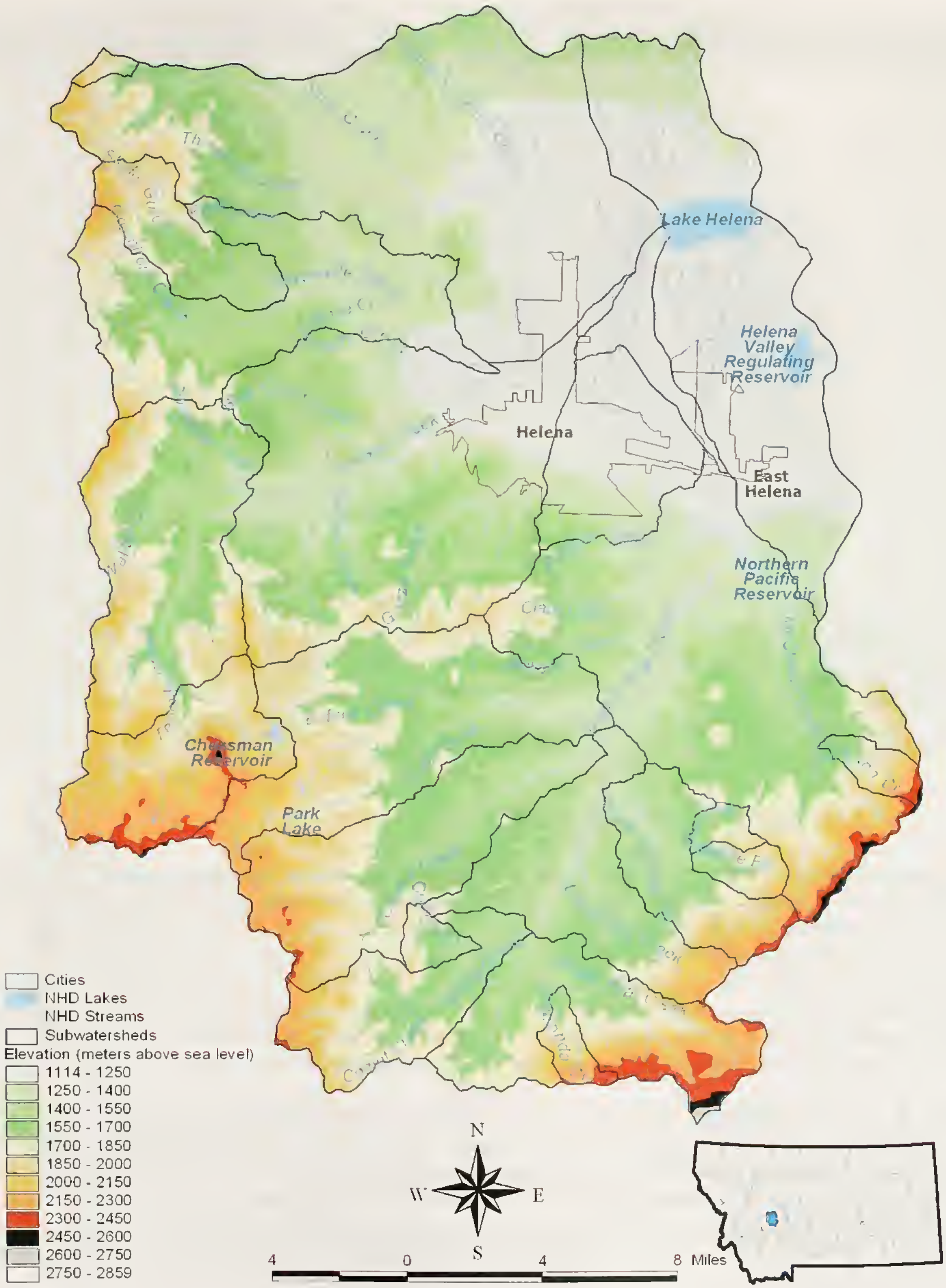


Figure 2. Lake Helena DEM, NHD Stream Coverage, and Subwatersheds

Table 2. Drainage Area and Mean Elevation of the Lake Helena Subwatersheds

Subwatershed	Watershed Area (ac)	Mean Elevation (m)	Corresponding Segment
Clancy Creek	21,140	1757.5	MT41I006_120
Corbin Creek	1,715	1685.2	MT41I006_090
Golconda Creek	1,887	1962.2	MT41I006_070
Jackson Creek	2,148	1924.2	MT41I006_190
Jennies Fork	670	1855.5	MT41I006_210
Overland flow to Lake Helena	38,330	1196.0	Overland flow
Lump Gulch	27,762	1722.3	MT41I006_130
Middle Fork Warm Springs	2,180	1796.9	MT41I006_100
Middle Tenmile Creek	24,701	1730.0	MT41I006_142
North Fork Warm Springs Creek	1,343	1721.7	MT41I006_180
Prickly Pear above Spring Creek	17,070	1866.7	MT41I006_060
Prickly Pear above Lake Helena	4,201	1134.6	MT41I006_020
Prickly Pear above Lump Gulch	16,275	1581.2	MT41I006_050
Prickly Pear above WWTP outfall	12,431	1294.0	MT41I006_030
Prickly Pear above Wylie Drive	47,176	1554.9	MT41I006_040
Sevenmile Creek	24,883	1527.6	MT41I006_160
Silver Creek	59,013	1355.4	MT41I006_150
Skelly Gulch	7,834	1700.6	MT41I006_220
Spring Creek	11,620	1758.4	MT41I006_080
Tenmile above Prickly Pear	48,786	1455.1	MT41I006_143
Upper Tenmile Creek	14,106	2068.3	MT41I006_141
Warm Springs Creek	9,670	1688.2	MT41I006_110
Total Watershed Area	393,445	na	na

2.1.2 Land Use in the Lake Helena Watershed

Existing land use and land cover in the Lake Helena Watershed were determined from satellite imagery, digital aerial photography, and geographic information system (GIS) layers. Digital land use/land cover data were obtained from the National Land Cover Dataset (NLCD). The NLCD is a consistent representation of land cover for the conterminous United States generated from classified 30-meter resolution Landsat thematic mapper satellite imagery data. The NLCD is classified into urban, agricultural, forested, water, and transitional land cover subclasses. The imagery was acquired by the Multi-Resolution Land Characterization (MRLC) Consortium, a partnership of federal agencies that produce or use land cover data. The imagery was acquired between 1991 and 1993.

MRLC data and corresponding land use classifications served as the primary basis for the GWLF modeling effort; however updates to the original data and refinements of land use categories were made to reflect current conditions in the Lake Helena watershed. 2004 high-resolution color orthophotos of the Helena Valley were used to manually classify a portion of the watershed using the land use definitions provided by the MRLC Consortium data description. Road areas and corresponding road surface materials in the watershed were distinguished based on GIS data layers acquired from Lewis and Clark and Jefferson counties and the Helena National Forest. Additionally, a new class of low-intensity residential development was added to reflect the low-density style of land development in the more rural areas of the Lake Helena Watershed. Figure 3 shows the final land use coverage and the data are summarized in Table 3.

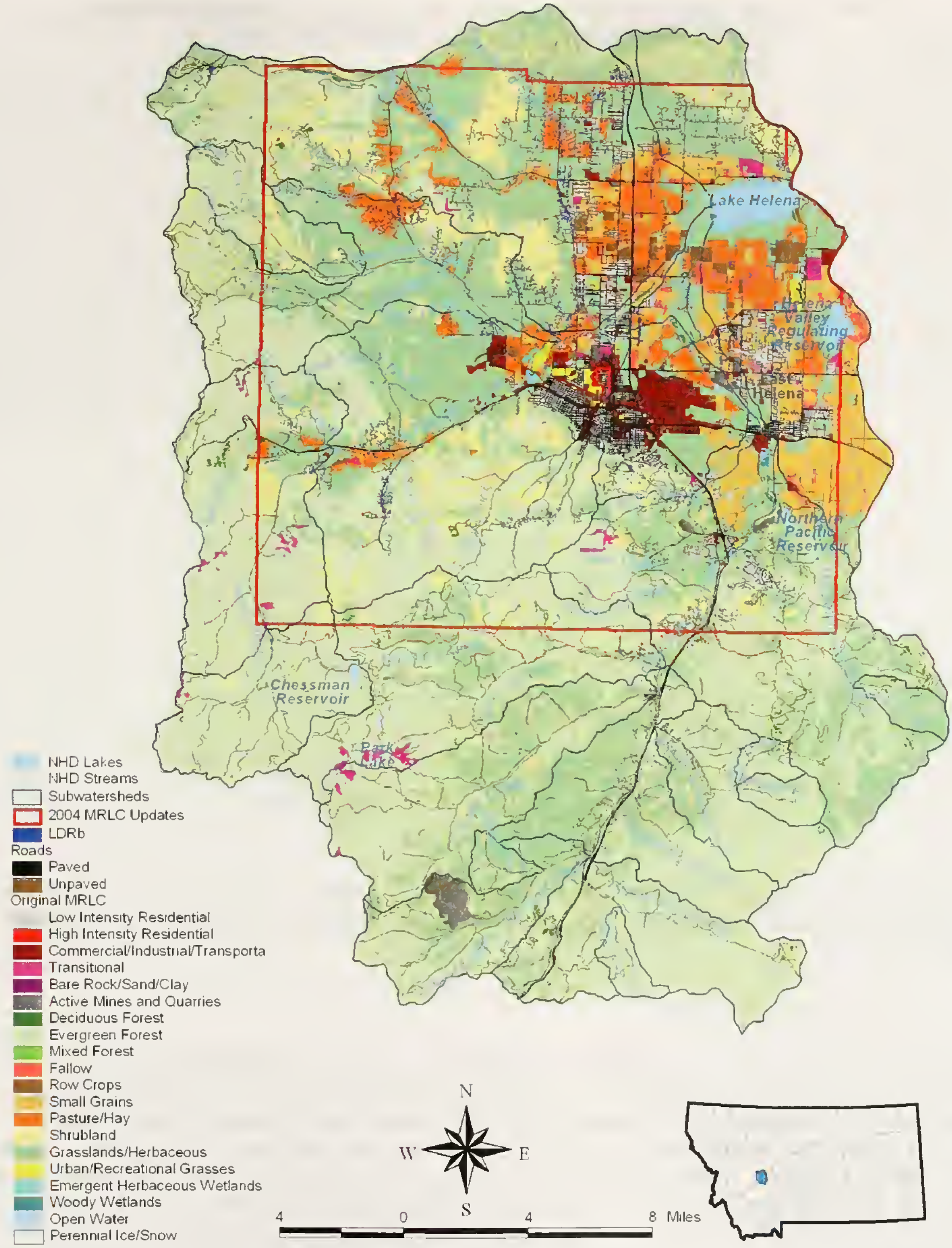


Figure 3. Land Use in the Lake Helena Watershed (Area Highlighted in Red was Updated Based on 2004 Aerial Photography)

Table 3. Land Use Areas for the Lake Helena Existing Conditions Modeling

Land Use	Existing (ac)
Bare Rock	84
LDRa	9,067
Quarries	234
Water	2,875
Transitional	1,853
Deciduous Forest	1,241
Evergreen Forest	154,204
Mixed Forest	36
Shrubland	37,014
Grassland	129,060
Pasture/Hay	14,892
Small Grains	16,925
Woody Wetland	1,270
Herbaceous Wetlands	421
Recent Clear-cut	522
Clear-cut Regrowth	3,571
Dirt Roads	3,326
Fallow	2,546
Row Crop	2,093
Non-system Roads	153
LDRb	2,950
Commercial/Industrial/Transportation	6,203
Urban/Recreational Grasses	1,001
Secondary Paved Roads	1,904
Total Watershed Area	393,445

All of the land use categories used for the modeling are standard MRLC classifications except for two low-intensity residential classifications, two silviculture classes, and three road classes, as described below.

2.1.2.1. Residential Lands

Low-intensity development was classified as either LDRa or LDRb to differentiate between the concentration of low density housing in and around the municipalities and the low-density housing development in the remainder of the watershed. LDRa represents developments detected during the orthophoto analysis or present in the original MRLC data set, with approximately 40 percent impervious area and 60 percent lawn. LDRb was created by buffering the remaining residential areas outside of the LDRa area to 1.1-acre lots (represented by structures for Lewis and Clark County and wells for Jefferson County). A 1.1 acre buffer radius was chosen based on the median value of developed area for 100 randomly selected parcels outside of the LDRa areas. Based on the analysis of the 100 random parcels, LDRb lots were assigned 40 percent impervious (house, barn, sheds), 24 percent pasture with poor ground cover (animal paddocks), and 36 percent lawn in good condition.

2.1.2.2. Forest Lands

To account for harvesting activities in the watershed, forest was modeled in one of three categories: (1) clear-cut, (2) regrowth, or (3) full growth condition. Forestland in the Lake Helena Watershed is owned by private land owners, the Bureau of Reclamation, Department of Natural Resources, Bureau of Land Management, and the Helena National Forest (Figure 4). Databases were obtained from each agency to estimate average harvest acreages for the period between 1996 and 2000 (Table 4). The public agencies use selective cut techniques rather than clear cutting procedures, so harvest acres were assumed in the regrowth state after cutting. Cutting has not occurred on land owned by the Helena National Forest since 1996. No data were obtained from the Bureau of Reclamation despite numerous requests. Harvest data on private lands was not available, so a continuous 90-yr harvesting cycle (Stuart, 2004) was assumed (i.e., 1.1 percent of private forest land was assumed clear cut each year). To estimate the area of regrowth on private lands, we assumed a 5 year regrowth period to re-establish full growth ground cover. The curve numbers, cover factors, and nutrient runoff concentrations of these silvicultural land uses vary from typical forestland as described in Table 5, Table 7, and Table 9.

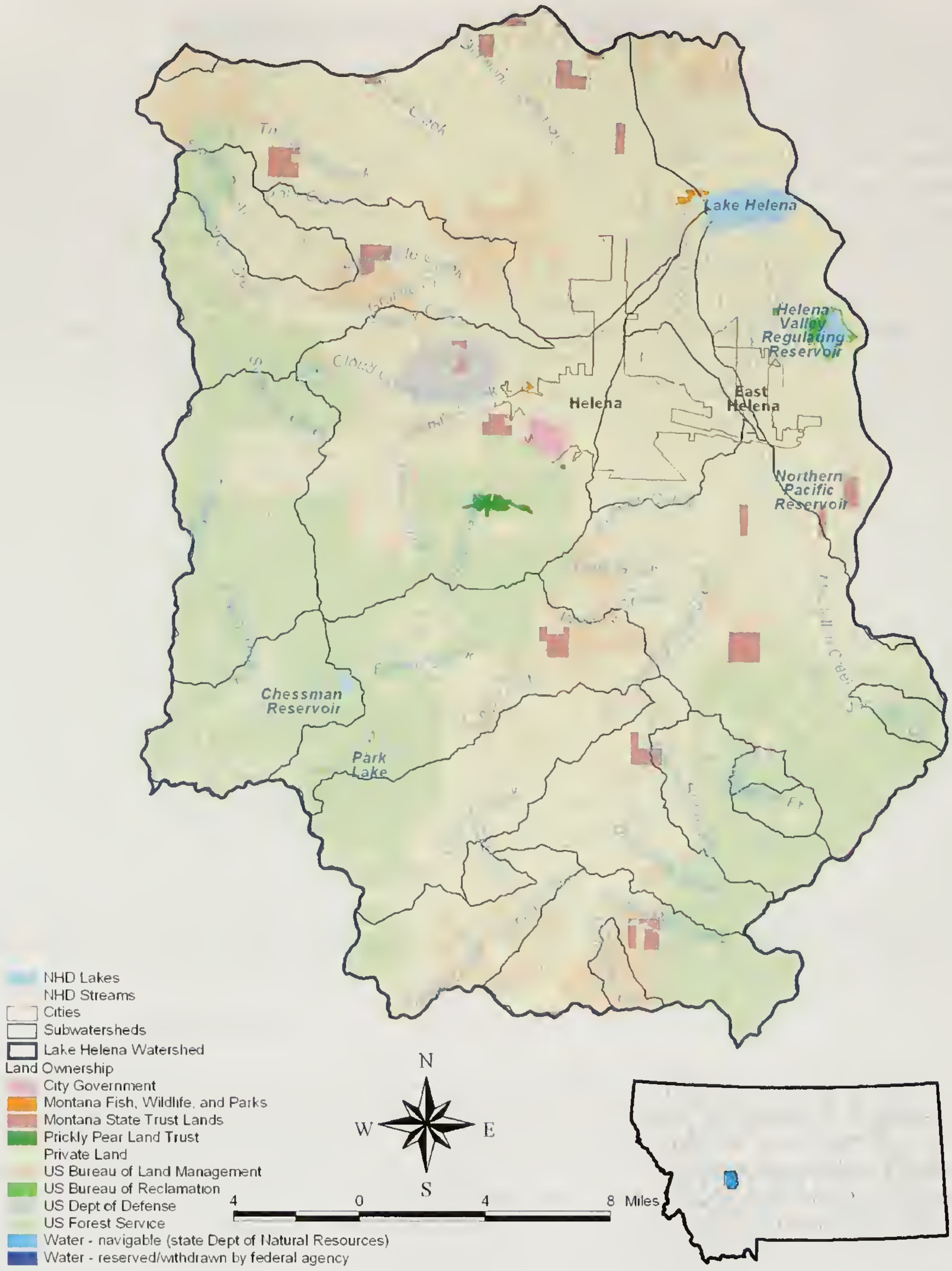


Figure 4. Land Ownership in the Lake Helena Watershed

Table 4. Harvest Data by Agency in the Lake Helena Watershed for the period 1996 to 2000.

Agency	Selective Harvest or Regrowth (ac)	Clear Cut (ac)
Bureau of Land Management	767	0
Bureau of Reclamation	0	0
Helena National Forest	0	0
Department of Natural Resource Conservation	195	0
Private	2,610	522

2.1.2.3. Roads

Road areas in the Lake Helena watershed were generated from current GIS data. The road polylines were converted into areas based on average widths from field data collected in 2005. Unpaved roads were buffered to a total width of 22 feet, and paved roads were buffered to a total width of 26 feet. Interstate 15 and Highway 12 are simulated with a width of 52 feet.

Non-system roads are those built for recreational purposes (dirt bikes, four wheelers, etc.) and are not built to approved specifications. Road slope is assumed to follow the land gradient rather than incorporate switch-backs. Ditches and cross drains are not present. In the Helena National Forest, non-system roads were estimated to comprise an additional 4.6 percent of the area of unpaved roads (Stuart, 2004). This value was extrapolated to the entire Lake Helena Watershed where unpaved roads are present.

2.1.2.4. Land Use Curve Numbers

The GWLF model uses the curve number method to estimate runoff from each land use area. Land uses with higher curve numbers are assumed to have more surface runoff than those with lower curve numbers. Table 5 lists the curve numbers by soil hydrologic group for land uses in the Lake Helena Watershed. Area weighted curve numbers were developed for each subwatershed and land use based on the reported NRCS soil hydrologic groups. Soil hydrologic groups were used to account for the different infiltration rates of different soil types (e.g., higher infiltration for sands compared to clays).

Table 5. SCS Curve Numbers for Land Uses in the Lake Helena Watershed

Land Use	CNa	CNb	CNc	CNd
Bare Rock	98	98	98	98
LDRa	63	76	84	87
Quarries	76	85	89	91
Water	100	100	100	100
Transitional	77	86	91	94
Deciduous Forest	30	55	70	77
Evergreen Forest	36	60	73	79
Mixed Forest	33	57	72	78
Shrubland	30	48	65	73
Grassland – Existing	49	69	79	84
Grassland - Natural	39	61	74	80
Pasture/Hay	30	58	71	78
Small Grains	63	75	83	87
Woody Wetland	98	98	98	98
Herbaceous Wetlands	98	98	98	98
Recent Clear-cut	77	86	91	94
Clear-cut Regrowth	57	73	82	87
Dirt Roads	72	82	87	89
Fallow	77	86	91	94
Row Crop	67	78	85	89
Non-system Roads	72	82	87	89
LDRb	69	39	39	39
Commercial/Industrial/Transportation	89	92	94	95
Urban/Recreational Grasses - fair condition	49	69	79	84
Secondary Paved Roads	98	98	98	98

2.1.3 USLE Parameters

GWLF uses the Universal Soil Loss Equation (USLE) to estimate soil erosion rates based on rainfall intensity, soil erodibility, slope length, gradient, and cover and management factors. Seasonal rainfall erosivity factors were developed based on regional values available from the GWLF User's Manual. The NRCS soils database (Figure 5) was used to estimate the average land slope in each subwatershed as well as area-weighted soil erodibility factors and length-slope factors (Table 6).

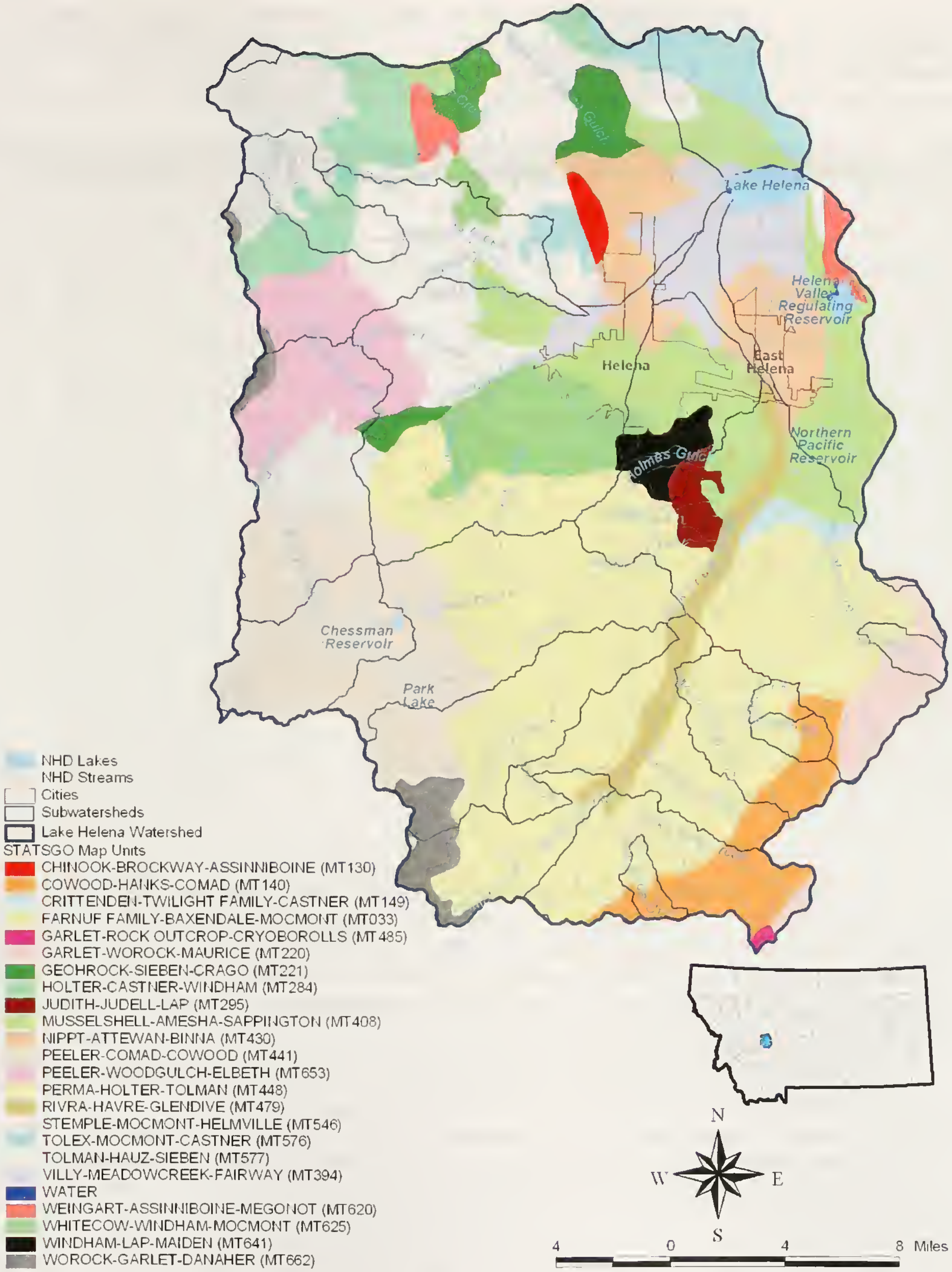

Lake Helena
Helena Valley Regulating Reservoir
Helena
East Helena
Northern Pacific Reservoir
Holmes Gulch
Gulch
Chessman Reservoir
Park Lake
NHD Lakes
NHD Streams
Cities
Subwatersheds
Lake Helena Watershed
STATSGO Map Units
CHINOOK-BROCKWAY-ASSINNIBOINE (MT130)
COWOOD-HANKS-COMAD (MT140)
CRITTENDEN-TWILIGHT FAMILY-CASTNER (MT149)
FARNUF FAMILY-BAXENDALE-MOCMONT (MT033)
GARLET-ROCK OUTCROP-CRYOBOROLLS (MT485)
GARLET-WOROCK-MAURICE (MT220)
GEOHROCK-SIEBEN-CRAGO (MT221)
HOLTER-CASTNER-WINDHAM (MT284)
JUDITH-JUDELL-LAP (MT295)
MUSSELSHELL-AMESHA-SAPPINGTON (MT408)
NIPPT-ATTEWAN-BINNA (MT430)
PEELER-COMAD-COWOOD (MT441)
PEELER-WOODGULCH-ELBETH (MT653)
PERMA-HOLTER-TOLMAN (MT448)
RIVRA-HAVRE-GLENDIVE (MT479)
STEMPLE-MOCMONT-HELMVILLE (MT546)
TOLEX-MOCMONT-CASTNER (MT576)
TOLMAN-HAUZ-SIEBEN (MT577)
VILLY-MEADOWCREEK-FAIRWAY (MT394)
WATER
WEINGART-ASSINNIBOINE-MEGONOT (MT620)
WHITECOW-WINDHAM-MOCMONT (MT625)
WINDHAM-LAP-MAIDEN (MT641)
WOROCK-GARLET-DANAHER (MT662)
N
W
E
S
4
0
4
8 Miles

Figure 5. STATSGO Soil Types in the Lake Helena Watershed

Slope lengths were set to 30 meters, which is a general default value for GWLF. Length-slope factors were developed using the revised USLE approach (Schwab et al., 1993), which is preferred by the Montana NRCS (Tom Pick, Water Quality Specialist, NRCS Montana State Office, personal communications, August 9, 2005).

Table 6. Average Land Slopes, Soil Erodibility Factors, and Length-Slope Factors by Subwatershed

Subwatershed	Land Slope (%)	K	LS
Clancy Creek	31.3	0.154	5.547
Corbin Creek	27.6	0.152	4.855
Golconda Creek	31.5	0.133	5.582
Jackson Creek	44.6	0.148	7.866
Jennies Fork	45.0	0.134	7.927
Lake Helena overland flow	9.3	0.279	1.239
Lump Gulch	29.3	0.142	5.170
Middle Fork Warm Springs	31.0	0.134	5.494
Middle Tenmile Creek	33.3	0.143	5.914
North Fork Warm Springs Creek	26.9	0.147	4.721
Prickly Pear above Spring Creek	30.7	0.140	5.432
Prickly Pear above Lake Helena	1.0	0.313	0.145
Prickly Pear above Lump Gulch	21.1	0.184	3.596
Prickly Pear above WWTP outfall	13.9	0.280	2.152
Prickly Pear above Wylie Drive	23.6	0.194	4.080
Sevenmile Creek	25.8	0.186	4.520
Silver Creek	19.6	0.214	3.306
Skelly Gulch	34.6	0.165	6.152
Spring Creek	33.2	0.176	5.889
Tenmile above Prickly Pear	21.9	0.206	3.750
Upper Tenmile Creek	37.5	0.120	6.663
Warm Springs Creek	27.5	0.148	4.840

Most of the subwatersheds have relatively high land slopes that would not accommodate properly designed unpaved roads. An average of the land slope and measured road slope at stream crossings was therefore used to estimate average road slopes. Measured slopes at stream crossings were obtained from a stream-crossing sediment loading analysis performed with the WEPP model as a part of the TMDL study (see Appendix D). Non-system roads were modeled without accounting for switch-back reduction of slope.

Cover factors for each land use are based on values suggested in Agriculture Handbook 537 (Wischmeier and Smith, 1978) and are summarized in Table 7. Under natural conditions, only forest, wetlands, shrubland, grassland, barerock, and water are simulated. The Upper Yellowstone River Watershed Land Cover Assessment report (NRCS, 2003) was used to develop modeling parameters for these land uses under natural conditions. The report states that in this relatively undisturbed watershed, grassland has 20 percent bare ground cover, shrubland has 10 percent bare ground cover, and forest has 10 percent bare ground cover. Under existing conditions, the bare ground cover was assumed 30 percent for grassland and 20 percent for shrubland to reflect higher animal densities and human disturbance. Cover factors for grassland were increased from 0.013 to 0.0275 from natural to existing conditions; cover factors for shrubland were increased from 0.006 to 0.012. The percent bare ground cover in full-growth forest was not assumed to increase because human impacts are being simulated with the clear-cut and regrowth classifications.

The cover factor for dirt roads is based on a literature value (Sun and McNulty, 1998).

Table 7. Cover Factors by Land Use in the Lake Helena Watershed

Land Use	Cover Factor
Bare Rock	0.0001
LDRa	0.0078
Quarries	1.0000
Water	0.0000
Transitional	0.0910
Deciduous Forest	0.0030
Evergreen Forest	0.0030
Mixed Forest	0.0030
Shrubland - Existing	0.0120
Shrubland - Natural	0.0060
Grassland – Existing	0.0275
Grassland – Natural	0.0130
Pasture/Hay	0.0420
Small Grains	0.3800
Woody Wetland	0.0030
Herbaceous Wetlands	0.0030
Recent Clear-cut	0.4500
Clear-cut Regrowth	0.1500
Dirt Roads	0.7500
Fallow	1.0000
Row Crop	0.5400
Non-system Roads	0.7500
LDRb	0.0265
Commercial/Industrial/Transportation	0.1000
Urban/Recreational Grasses	0.0130
Secondary Paved Roads	0.2500

The USLE equation estimates average annual erosion rates. Delivered sediment is estimated by applying a sediment delivery ratio which is calculated for each subwatershed based on drainage area as suggested in Haith et al. (1992) and summarized in Table 8. Larger watersheds have smaller delivery ratios.

Table 8. Sediment Delivery Ratios for the Lake Helena Subwatersheds

Subwatershed	Sediment Delivery Ratio
Clancy Creek	0.1335
Corbin Creek	0.2386
Golconda Creek	0.2339
Jackson Creek	0.2277
Jennies Fork	0.2881
Lake Helena overland flow	0.1134
Lump Gulch	0.1241
Middle Fork Warm Springs	0.2270
Middle Tenmile Creek	0.1281
North Fork Warm Springs Creek	0.2509
Prickly Pear above Spring Creek	0.1411
Prickly Pear above Lake Helena	0.1970
Prickly Pear above Lump Gulch	0.1428
Prickly Pear above WWTP outfall	0.1528
Prickly Pear above Wylie Drive	0.1067
Sevenmile Creek	0.1278
Silver Creek	0.0998
Skelly Gulch	0.1708
Spring Creek	0.1554
Tenmile above Prickly Pear	0.1057
Upper Tenmile Creek	0.1481
Warm Springs Creek	0.1625

2.1.4 Soil Water Capacity and River Recession

Water stored in soil may evaporate, be transpired by plants, or percolate to ground water below the rooting zone. The amount of water that can be stored in soil (the soil water capacity) varies by soil type and rooting depth. Based on soil water capacities reported in the STATSGO database, soil types present in the watershed, and GWLF user's manual recommendations, a GWLF soil water capacity of 10 cm was used.

The GWLF model has three subsurface zones: a shallow unsaturated zone, a shallow saturated zone, and a deep aquifer zone. Behavior of the second two stores is controlled by a ground water recession and a deep seepage coefficient. The recession coefficient was set to 0.01 per day and the deep seepage coefficient to 0, based on several calibration runs of the model.

2.2 Weather Data

The GWLF model uses daily estimates of precipitation and average temperature to estimate water inputs to the system as well as potential evapotranspiration rates. Weather data from the Helena Regional Airport (Coop ID 244055; elevation 1,167 m) was used to develop a 20-year input file from January 1980 through December 2003.

The mean elevation of each subwatershed was used to account for elevation effects on temperature and precipitation based on a comparison of mean annual precipitation and temperature at Austin, Montana

(Coop ID 240375; elevation 1,493 m). For each meter increase in elevation, 0.03 cm/yr of precipitation were added and 0.0038 °C were subtracted from the daily average temperature.

SNOTEL data were not adequate to develop daily weather inputs for the high elevation subwatersheds because cumulative precipitation estimates showed losses due to sublimation, which would not occur over an entire modeling subwatershed. However, annual average precipitation at the Frohner station was used to validate the elevation adjustments cited above. In general, yearly precipitation at Frohner was more stable than at the airport. Even though elevation effects were accounted for, dry years at the airport (1994 and 1995) generally result in an underestimation of precipitation in the high elevation subwatersheds and an over prediction in extremely wet years (1993) (Figure 6).

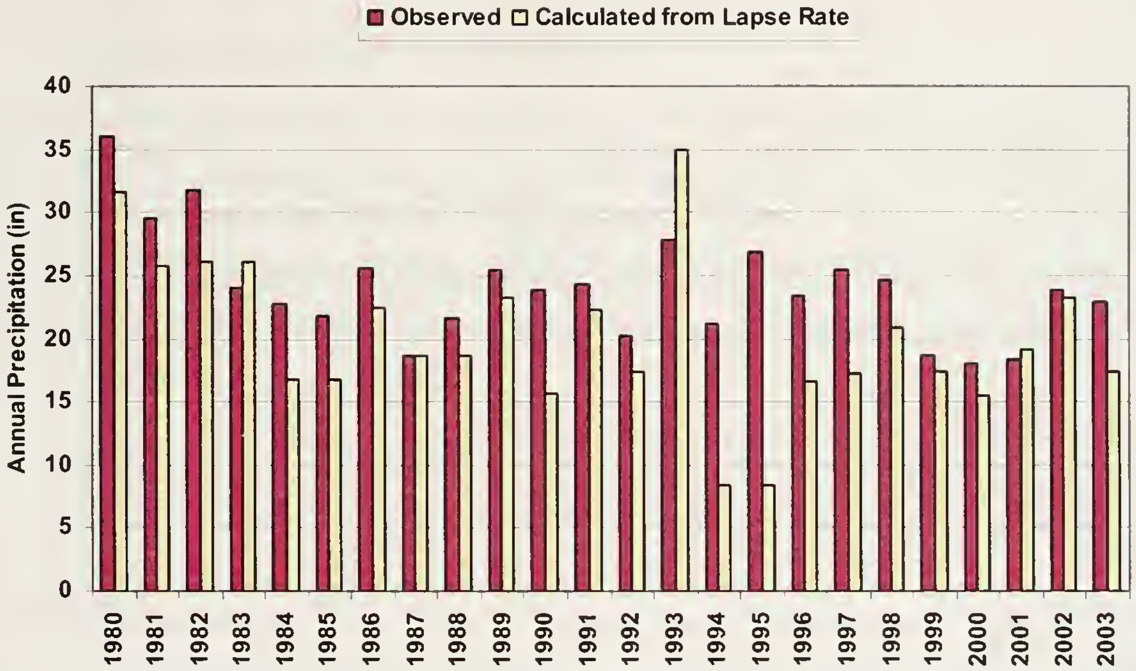


Figure 6. Comparison of Observed and Estimated Precipitation at the Frohner SNOTEL Station

2.3 Nutrient Data

The GWLF model simulates nutrient runoff from rural land uses and washoff from urban land uses. In addition, soil is assumed to carry sorbed nutrients; groundwater also serves as a component of the total load.

2.3.1 Soil Nutrient Concentrations

Because site-specific data were not available, soil nutrient concentrations are based on spatial distributions provided in the GWLF manual. Both the soil nitrogen and soil phosphorus concentrations were set to the lower end of the suggested range for the geographic area during model calibration (Section 2.6.2). The soil nitrogen concentration is estimated to be 2,000 mg/kg and the soil phosphorus concentration is estimated to be 440 mg/kg.

2.3.2 Runoff Concentrations from Rural Land Uses

Dissolved nutrient concentrations in runoff from each land use were set to GWLF default values and are summarized in Table 9. Because site-specific data were not available, default values were chosen to estimate relative contributions from the pollutant sources. Best professional judgment was used to estimate runoff concentrations from dirt roads.

Table 9. Nutrient Runoff Concentrations for Rural Land Uses in the Lake Helena Watershed

Land Use	Nitrogen (mg/L)	Phosphorus (mg/L)
Bare Rock	0.01	0.001
LDRa	1.72	0.094
Quarries	0.01	0.001
Water	0.07	0.012
Transitional	1.00	0.100
Deciduous Forest	0.07	0.012
Evergreen Forest	0.07	0.012
Mixed Forest	0.07	0.012
Shrubland	0.70	0.010
Grassland	0.60	0.070
Pasture/Hay	3.00	0.250
Small Grains	1.80	0.300
Woody Wetland	0.07	0.012
Herbaceous Wetlands	0.07	0.012
Recent Clear-cut	2.60	0.100
Clear-cut Regrowth	1.30	0.056
Dirt Roads	0.10	0.010
Fallow	2.60	0.100
Row Crop	2.90	0.260
Non-system Roads	0.10	0.010
LDRb	2.01	0.170

2.3.3 Buildup Washoff Rates from Urban Land Uses

GWLF simulates nutrient loads from developed land uses through a buildup/washoff formulation. Buildup rates for nitrogen and phosphorus are based on weighted averages of pervious and impervious default values suggested in the GWLF manual (Table 10).

Table 10. Buildup Washoff Rates for Urban Land Uses in the Lake Helena Watershed

Land Use	Nitrogen (kg/ha-d)	Phosphorus (kg/ha-d)
Commercial/Industrial/Transportation	0.05	0.005
Urban/Recreational Grasses	0.012	0.0016
Secondary Paved Roads	0.1	0.01

2.3.4 Groundwater Nutrient Concentrations

Groundwater nutrient concentrations were based on baseflow measurements reported in the GWLF manual for various levels of forested and agriculturally developed watersheds. Completely forested watersheds have values of 0.07 mg-N/L and 0.012 mg-P/L. Primarily agricultural watersheds have values of 0.71 mg-N/L and 0.104 mg-P/L. Intermediary values are also reported. Values for each subwatershed were assigned based on the percent forest and agricultural land use in the watershed (Table 11). For the natural scenario, all subwatersheds were assumed to have concentrations reported for primarily forested watersheds. Groundwater loads from the Helena Valley Irrigation District were modeled separately as discussed in Section 2.4.4.

Table 11. Estimated Groundwater Nutrient Concentrations for the Lake Helena Subwatersheds Under Existing Conditions

Subwatershed	Groundwater Nitrogen Concentration (mg-N/L)	Groundwater Phosphorus Concentration (mg-P/L)
Clancy Creek	0.18	0.015
Corbin Creek	0.18	0.015
Golconda Creek	0.07	0.012
Jackson Creek	0.18	0.015
Jennies Fork	0.18	0.015
Lake Helena overland flow	0.83	0.083
Lump Gulch	0.18	0.015
Middle Fork Warm Springs	0.07	0.015
Middle Tenmile Creek	0.07	0.015
North Fork Warm Springs Creek	0.07	0.015
Prickly Pear above Spring Creek	0.07	0.015
Prickly Pear above Lake Helena	0.83	0.083
Prickly Pear above Lump Gulch	0.18	0.015
Prickly Pear above WWTP outfall	0.83	0.083
Prickly Pear above Wylie Drive	0.18	0.015
Sevenmile Creek	0.18	0.015
Silver Creek	0.18	0.015
Skelly Gulch	0.18	0.015
Spring Creek	0.18	0.015
Tenmile above Prickly Pear	0.18	0.015
Upper Tenmile Creek	0.07	0.015
Warm Springs Creek	0.18	0.015

2.3.5 Septic System Loading Data

The GWLF model requires an estimation of population served by septic systems to generate septic system nutrient loading rates. Lewis and Clark County maintains a GIS coverage of permitted septic systems and reports that permitted systems are approximately 63 percent of the total number of systems in the watershed (LCCHD, 2002). The number of permitted systems within Lewis and Clark County was scaled up accordingly to estimate the total number of systems in each subwatershed for the existing scenario.

A GIS coverage of permitted septic systems was not available for Jefferson County. However, both Lewis and Clark and Jefferson Counties maintain geographic databases of wells that were available to the project team. The average ratio of septic systems to wells in Lewis and Clark County was determined to be 0.86 by comparing the two databases. Based on the assumption that most houses with wells will also have a septic system, this ratio was applied to the number of wells on record for each subwatershed in Jefferson County to estimate the total number of septic systems. Figure 7 shows the permitted septic systems in Lewis & Clark County and the wells coverage for the entire watershed.

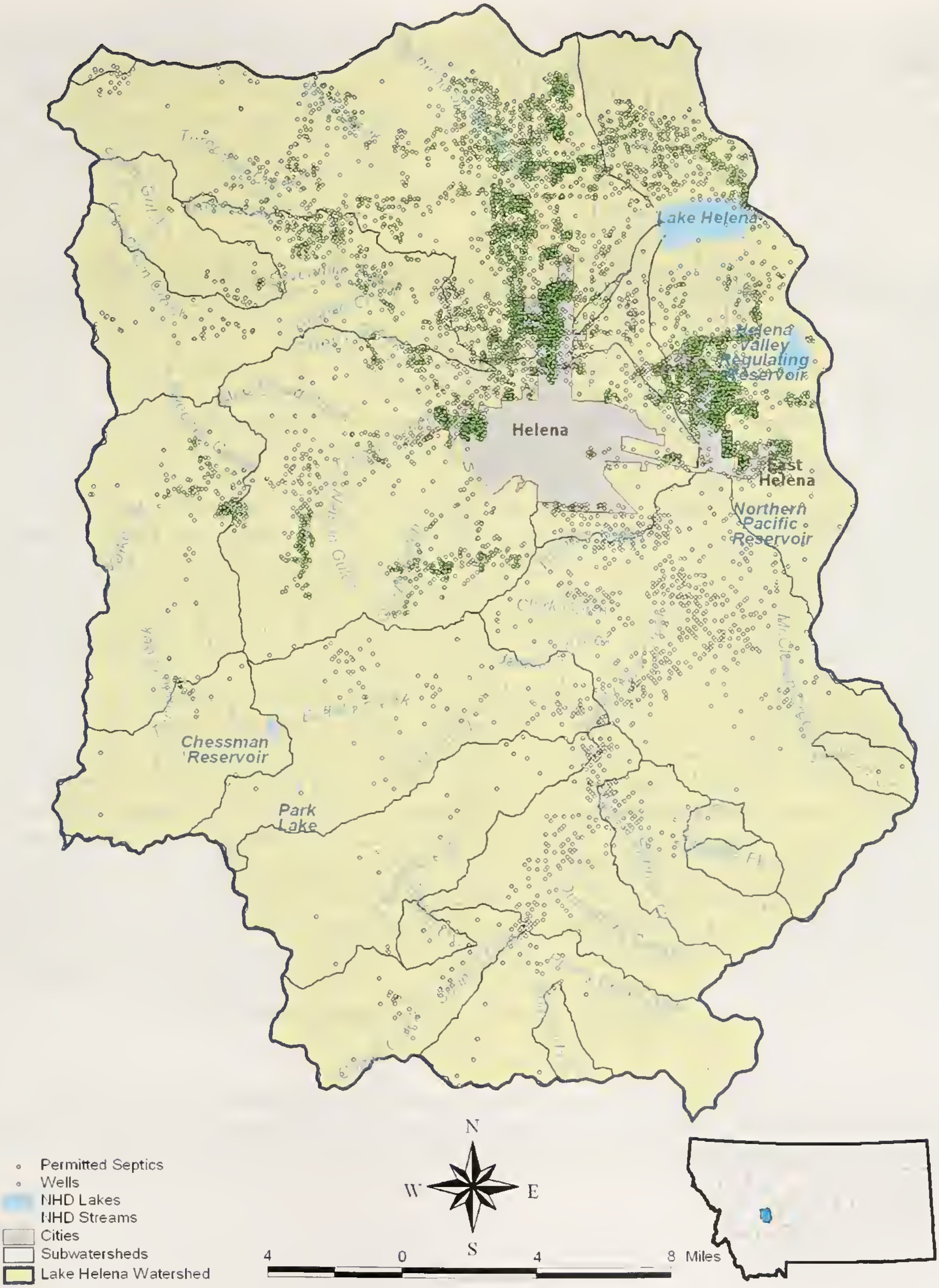


Figure 7. Permitted Septic Systems in Lewis & Clark County and Wells Coverage for the Watershed

To convert the number of septic systems to population served, an average household size of 2.5 people per dwelling was used based on Census data. GWLF also requires an estimate of the number of normal and failing septic systems. This information was requested of the county health departments but was not available. It was therefore assumed that 7 percent of all systems were failing based on the reported national average (USEPA, 2002b). A failing system is assumed to short circuit the drainfield and plant uptake zones and discharge directly to the groundwater. The population served by normal and failing systems is summarized by subwatershed in Table 12.

Table 12. Population Served by Septic Systems in the Lake Helena Watershed

Subwatershed	Normally Functioning	Failing[a]	Total
Clancy Creek	88	7	94
Corbin Creek	12	1	13
Golconda Creek	4	0	4
Jackson Creek	4	0	4
Jennies Fork	20	2	21
Lake Helena overland flow	4875	367	5,242
Lump Gulch	245	18	264
Middle Fork Warm Springs	0	0	-
Middle Tenmile Creek	207	16	222
North Fork Warm Springs Creek	2	0	2
Prickly Pear above Spring Creek	90	7	96
Prickly Pear above Lake Helena	513	39	552
Prickly Pear above Lump Gulch	474	36	510
Prickly Pear above WWTP outfall	447	34	480
Prickly Pear above Wylie Drive	1605	121	1,725
Sevenmile Creek	517	39	556
Silver Creek	8340	628	8,968
Skelly Gulch	48	4	52
Spring Creek	161	12	174
Tenmile above Prickly Pear	3004	226	3,230
Upper Tenmile Creek	26	2	28
Warm Springs Creek	157	12	169
Total	20,839	1,568	22,407

[a] Assumed 7 percent of onsite systems are failing based on national average (USEPA, 2002b).

Daily per capita mass loading rates and plant uptake rates for normal and failing systems were set to GWLF default values and are summarized in Table 13. Using the default parameters suggested by the manual allows for an estimation of pollutant loading relative to other sources in the watershed.

Table 13. Septic System Loading Rates and Plant Uptake Rates

Parameter	Nitrogen	Phosphorus
Loading Rate from Septic Tank Prior to Drainfield Treatment and Plant Uptake (grams/capita/day)	12	1.5
Growing Season Plant Uptake Rate (grams/capita/day)	1.6	0.4
Dormant Season Plant Uptake Rate (grams/capita/day)	0	0
Percent Additional Treatment in Soil Adsorption Field of Normal System (%)	0	100
Percent Additional Treatment in Soil Adsorption Field of Failing System (%)	0	0

Note that normal and failing systems are assumed to have the same tank effluent loading rates. In a normally functioning system, tank effluent is distributed over a soil drainfield. Phosphorus is assumed completely adsorbed to the soil particles and some nitrogen is taken up by plant roots during the growing season. The failing system bypasses both of these treatment mechanisms and is assumed to discharge pollutants at rates equivalent to the tank effluent values. Appendix K gives a more thorough description of septic system design and water quality impacts as well as a comparison of loading rates from conventional septic systems, Level 2 treatment systems, and wastewater treatment plants.

Current estimated septic system loading rates by major subwatershed are presented in Table 14. The table also shows the impacts of 1) updating all failing systems to properly functioning conventional septic systems, 2) replacing all failing systems with a Level 2 treatment system (Appendix K), or 3) diverting the wastewater from households served by a failing system to the City of Helena WWTP. The diversion scenario is shown only for illustrative purposes and is not meant to infer a viable management strategy for failing onsite systems.

At the Lake Helena watershed scale, repairing or replacing failing systems with properly functioning onsite wastewater treatment systems (conventional or Level 2) will reduce the septic system nitrogen load by less than 2 percent and the cumulative nitrogen load by less than 1 percent. Diverting the flow from the failing systems to the City of Helena WWTP would result in a net reduction in nitrogen loading of approximately 2 percent. Phosphorus loads from septic systems would be reduced to zero in all three scenarios because the drainfields of normally functioning onsite systems are assumed to retain all phosphorus. At the Lake Helena watershed scale, phosphorus loads would decrease by approximately one-half a percent. The diversion scenario assumes that only failing systems are diverted to the plant. If normally functioning systems are assumed diverted, the net phosphorus load would increase because wastewater treatment plants discharge higher loads of phosphorus per person compared to properly functioning onsite systems.

Table 14. Comparison of Loading Rates from Septic Systems in the Lake Helena Watershed Under Four Failure Scenarios

Watershed	Current Septic System Loading Rate with 7 Percent Failure (mt/yr)	Load if Failing Systems are Updated to Properly Functioning Conventional Systems (mt/yr)	Load if Failing Systems are Replaced with Level 2 Systems (mt/yr)	Load if Failing Systems are Diverted to City of Helena WWTP (mt/yr)
Nitrogen				
Prickly Pear Creek	33.59	33.42	33.01	31.08
Sevenmile Creek	2.49	2.48	2.45	2.31
Spring Creek	0.77	0.76	0.75	0.71
Tenmile Creek	16.79	16.71	16.50	15.54
Lake Helena	92.06	91.60	90.46	85.19
Phosphorus				
Prickly Pear Creek	0.31	0.00	0.00	0.00
Sevenmile Creek	0.02	0.00	0.00	0.00
Spring Creek	0.01	0.00	0.00	0.00
Tenmile Creek	0.16	0.00	0.00	0.00
Lake Helena	0.86	0.00	0.00	0.00

Note: Diverting loads from failing systems to the City of Helena WWTP would result in an average annual increase in total nitrogen loading from the plant of 1.55 mt/yr and an increase in total phosphorus loading of 0.69 mt/yr.

2.3.6 Point Sources

There are nine centralized wastewater treatment systems in the Lake Helena Watershed (See Appendix E for information about each facility). The EPA point source database was used to obtain average flows and nutrient loads for the City of Helena, City of East Helena, and Evergreen Nursing facilities. Loads from the smaller systems were estimated by applying suggested nutrient concentrations reported in the 1997 USEPA publication, Technical Guidance Manual for Developing Total Maximum Daily Loads, Book 2: Streams and Rivers, which provides total nitrogen and total phosphorus concentrations from several studies following various treatment methods (Table 15). General facility information was obtained from the 1998 Helena Area Wastewater Treatment Facility Plan (Damschen & Associates, Inc., 1998).

As stated in Appendix E, three of the lagoon systems in the Lake Helena watershed (Tenmile/Pleasant Valley, Treasure State, and Leisure Village) appear to be functioning improperly, mostly because of excessive seepage from the system or insufficient storage capacity. Based on information in the Facility Plan, it was assumed that 75 percent of the stored water from the Tenmile/Pleasant Valley subdivision and the Leisure Village Mobile Home Park is seeping into the groundwater, and that the systems should only be seeping a maximum of 25 percent. The report did not state that Treasure State has excessive seepage, but rather insufficient storage capacity. Concentrations from Treasure State were simulated at "after sedimentation" concentrations rather than stabilized values. For TMDL allocations and reductions, these three systems were assumed to function as designed (Appendix A).

Table 15. Typical Nutrient Concentrations Reported in USEPA, 1997

Nutrient	Before Sedimentation	After Sedimentation	Stabilization Pond Effluent
Total Nitrogen (mg/L)	35	25	12-17
Total Phosphorus (mg/L)	10	8	5
Inorganic Nitrogen (mg/L)	16	8	5

Table 16 summarizes the average flows and nutrient loads from each facility for the existing scenario. Loads from the City of Helena WWTP are presented pre- and post-plant upgrades, which occurred in June 2001.

Table 16. Average Flow Rates and Annual Nutrient Loads from Centralized Wastewater Treatment Systems in the Lake Helena Watershed

Facility	Flow (MGD)	TN (mt/yr)	TP (mt/yr)
City of Helena: pre-upgrades	3.5	65.801	8.910
City of Helena: post-upgrades	3.5	28.801	12.230
East Helena: pre-upgrades	0.096	2.890	0.475
East Helena: post-upgrades	0.096	5.920	0.910
Evergreen Nursing Home	0.007	0.090	0.034
Eastgate Subdivision	0.15	0.060	0.104
Treasure State Acres subdivision	0.10	0.070	0.111
Tenmile and Pleasant Valley subdivisions	0.09	0.680	0.068
Leisure Village mobile home park	0.10	0.750	0.075
Mountain View law enforcement academy	0.007	0.140	0.048
Fort Harrison, national guard, VA center and hospital pre-closure	0.07	0.310	0.031

Flow volumes and nutrient loads from the City of Helena, City of East Helena, Treasure State Acres, Tenmile/Pleasant Valley, and Mountain View Academy are discharged to the Prickly Pear Creek above Lake Helena subwatershed. The Evergreen Nursing Home discharges to the Prickly Pear Creek above Lump Gulch subwatershed. East Gate Subdivision and Leisure Village discharge to the Lake Helena overland flow subwatershed. Facility locations are shown in Figure 8.

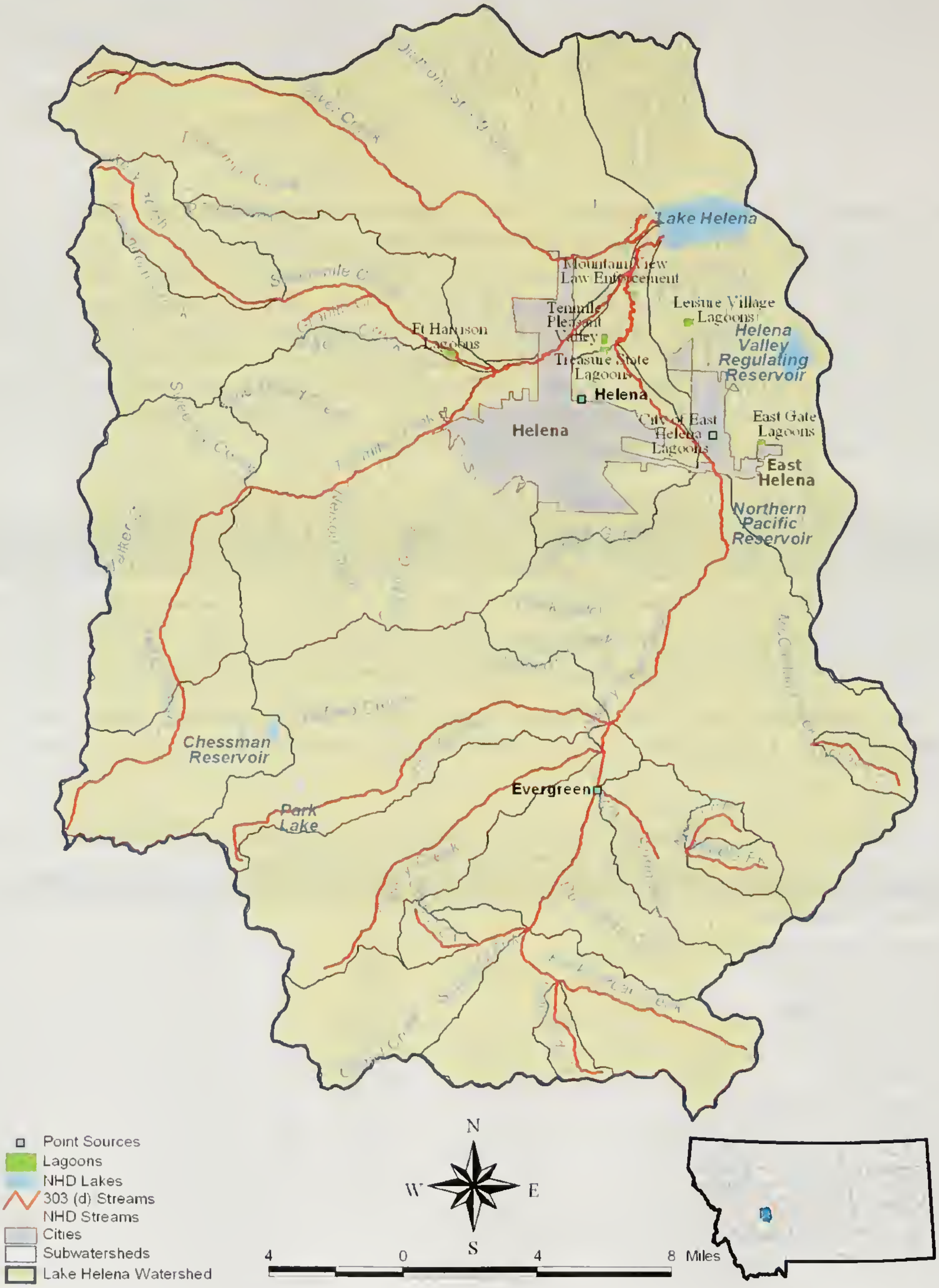


Figure 8. Location of Centralized Wastewater Facilities in the Lake Helena Watershed

2.4 Additional Considerations

The Lake Helena Watershed has several additional considerations that were accounted for in post-processing steps separate from the GWLF modeling. Assumptions regarding streambank erosion, drinking water plant diversions, abandoned mines, the Helena Valley Irrigation District, the City of Helena Stormwater System, and the existing sewer system are discussed in this section.

2.4.1 Streambank Erosion

Streambank erosion is an inherent part of channel evolution and can contribute significant quantities of sediment to stream systems based on a combination of climatic and physiographic features. However, anthropogenic impacts, such as grazing, mining, timber harvest, road encroachment, riparian vegetation removal, and/or channel alterations can result in elevated rates of streambank erosion. The intent of this analysis was to provide a sediment load estimate from streambank erosion within the listed watersheds. Modeled sediment load was allocated into two source categories: anthropogenic and natural.

Due to the size of the Lake Helena Watershed and the large number of listed stream miles, a coarse filter approach was used to estimate the sediment load related to streambank instability (See Appendix D). Bank Erosion Hazard Index (BEHI) assessments were conducted on intra-segment reaches to assess streambank erosion. Results from sampled reaches were averaged and extrapolated to the full perennial stream length within a listed stream segment's watershed. The BEHI assessments were based on a slightly modified version of the Rosgen (1996) method to characterize streambank conditions into numerical indices of bank erosion potential.

The modified BEHI methodology evaluated a streambank's inherent susceptibility to erosion as a function of six factors, including

- The ratio of streambank height to bankfull stage.
- The ratio of riparian vegetation rooting depth to streambank height.
- The degree of rooting density.
- The composition of streambank materials.
- Streambank angle (i.e., slope).
- Bank surface protection afforded by debris and vegetation.

To determine annual sediment load from eroding streambanks in each BEHI category, bank retreat rates developed by Rosgen (2001) were used (Table 17). The rate of erosion was then multiplied by the area of eroding bank (square feet) to obtain a volume of sediment per year, and then multiplied by the sediment density (average bulk densities were 1.41 g/cm^3 within granitic parent material, and 1.31 g/cm^3 outside of the batholith, U.S. Forest Service, 1998) to obtain a mass of sediment per year.

Table 17. Bank Retreat Rates Used for Banks of Varying Severity of Erosion

Bank Erosion Hazard Condition	Retreat Rate from Rosgen 2001 (ft/yr) – used for A and B channels	Retreat Rate from Rosgen 2001 (ft/yr) – used for C channels
Low	0.045	0.09
Moderate	0.17	0.34
High	0.46	0.7
Severe	0.82	1.2

Note: A, B, and C channels refer to Rosgen Stream Types.

Total sediment load from eroding streambanks of each sediment-listed stream was generated by averaging intra-segment (reach) sediment loads, and applying this value to the entire perennial segment length. For this purpose, each listed segment was divided into approximately 5 assessment reaches (actual number of reaches varied from 2 to 10) based on homogeneity of land use, vegetation and geomorphic character. Each listed reach outside the Helena National Forest boundary was visited, and BEHI measurements were conducted where eroding streambanks were observed.

In the reaches where bank instability was determined to be a significant source of sediment, a representative eroding streambank was surveyed using the BEHI methodology; the surveyors then extrapolated this bank configuration/condition for an identified percentage of the reach (or segment) length, which was observed through aerial photo assessment or direct visual assessment.

For example, if the BEHI analysis resulted in an average segment sediment load of 0.02 tons/foot/year from a segment's surveyed eroding streambank, the total channel length is 3 miles, and the condition of the surveyed eroding streambank represented 20 percent of the total channel length. (This 20 percent example relates to total eroding streambanks from river right and river left.) The 0.02 tons/foot/year is extrapolated to the entire eroding perennial streambank length of the segment; i.e., 20 percent of 3 miles (15,840 ft.) of streambank is 3,168 feet; applying the unit based sediment load of 0.02 tons (0.02 x 3168 ft) results in a total sediment load from eroding streambanks from this theorized segment of 63.4 tons/yr.

Additionally, the total sediment load related to eroding streambanks was allocated between naturally occurring and anthropogenically induced. This allocation was determined through observations during field reconnaissance and by aerial photo assessments. Land uses adjacent to, or in some cases upstream from, eroding streambanks were surveyed. The majority of land uses found to contribute to eroding streambanks included channel encroachment or sinuosity reductions related to transportation infrastructure, which includes interstate highways, city/county roads, forest roads, and rail-roads; riparian vegetation reduction caused by grazing in or near the riparian zones; and historic mining activities. Based on these assessment results, percentages of eroding bank lengths were generated and allocated to natural or anthropogenic sources within each segment.

Average BEHI ratings for all sediment listed segments varied between "moderate" and "high" for all the listed segments, however intra-segment reach BEHI ratings varied between "low" and "very high". Intra-segment variability was a product of heterogeneous land ownership and land use. BEHI rating and reach location were well correlated. Segments with BEHI ratings of "high" were largely confined to higher order stream segments lower in the watershed. Higher ordered segments tend to have finer substrate, and a greater intensity of land use, both, of which result in decreased streambank stability.

Sediment load from streambank erosion for the Lake Helena Watershed was estimated to be 6,162 metric tons/year. Of this total, 4,815 tons/year were generated within the Prickly Pear watershed, and the remaining 1,347 tons/year were generated within the Tenmile/Sevenmile watershed.

Streambank erosion was allocated between natural and anthropogenic sources by field and aerial assessment. Of the total sediment load (6,162 tons), 4,725 tons (approximately 77 percent) was related to anthropogenic activities; the remaining 1,438 tons (approximately 23 percent) was related to naturally occurring streambank erosion. The results of this analysis on a subwatershed basis are summarized below in Table 18.

Table 18. Sediment Loads from Eroding Streambanks by Source

Reach ID	Anthropogenic Related Eroding Banks (%)	Anthropogenic Sediment Load (mt/yr)	Natural Sediment Load (mt/yr)	Total Sediment Load (mt/yr)
Prickly Pear above Lake Helena	85%	516.6	91.2	607.8
Prickly Pear above WWTP	85%	20.5	3.6	24.1
Prickly Pear above Lump Gulch	100%	142.4	0.0	142.4
Prickly Pear above Spring Creek	55%	1134.7	928.4	2,063.1
Corbin Creek	90%	24.9	2.8	27.7
Spring Creek	95%	76.8	4.0	80.8
Clancy Creek	85%	1193.1	210.5	1,403.6
Warm Springs Creek	60%	35.1	23.4	58.5
Lump Gulch	80%	325.4	81.3	406.7
Middle Tenmile Creek	95%	296.8	15.6	312.4
Tenmile above Prickly Pear	95%	281.7	14.8	296.5
Skelly Gulch	45%	21.6	26.4	47.9
Sevenmile Creek	95%	652.2	34.3	686.5
Jennies Fork	70%	2.7	1.2	3.9

2.4.2 Upper Tenmile Creek Diversions

Drinking water for the City of Helena is processed at the City of Helena Tenmile Water Plant. During the summer months, the plant receives supplemental flows from the Missouri River Water Plant. The plant gets the majority of its water from head gates on Tenmile Creek, Beaver Creek, Minnehaha Creek, Moose Creek, and Walker Creek, which are all located in the Upper Tenmile subwatershed. Daily head gate flows were provided from the Tenmile Plant for January 1990 through June 2005. Flows and associated nutrient loads were subtracted from GWLF results on a monthly basis to account for these diversions.

2.4.3 Abandoned Mines

Sediment loads associated with abandoned mining were calculated for sites throughout the Lake Helena watershed. Potential sediment source locations were delineated from the High Priority Abandoned Hardrock Mine Sites, and Abandoned and Inactive Mines of Montana, as well as the National Hydrography Dataset GIS data layers. Potential sediment source delineation criteria were as follows: mine sites within 300 feet of a stream, or mines within 1,000 feet of a stream in areas where slopes are greater than 30 percent.

This GIS exercise generated 223 mines deemed to be potential sediment sources. These mines were cross-referenced with Montana Bureau of Mines and Geology (MBMG) reports, and the Montana State Bureau of Abandoned Mines. Available MBMG documents reported that 12 of the Abandoned-Inactive mines were probable sediment sources. Additionally, records of High Priority Abandoned Hardrock Mine Sites from the Montana State Bureau of Abandoned Mines indicated that 18 additional mine sites were probable sediment sources. Locations of sediment producing mines are shown in Figure 9. The

MBMG and Bureau of Abandoned Mine reports contained CAD drawings of the mine sites with areas and volumes of tailings and waste rock piles.

Area-based sediment loads for waste rock piles were obtained from a report produced by CDM, for USEPA, for use in the Upper Tenmile Creek Mining Area Superfund site. CDM used RUSLE version 1.06 to generate a sediment yield of 27 tons/acre/year from nose slopes, and 16 tons/acre/year from side slopes of waste rock piles in loamy-sand textured soil. Sediment delivery ratios were generated based on methodology described in *Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands* (Toy and Galetovic, 1999).

Five of the High Priority Abandoned Mine sites were reported to be reclaimed. The level of reclamation, and associated reduction in sediment production was assessed at each of the five sites. Of the five mine sites, only one (Alta) was not fully vegetated and continued to generate sediment. Pre- and post-reclamation sediment loads were calculated for reclaimed mine scenarios.

Table 19 and Table 20 describe the sediment loads associated with each mine site determined to be a sediment source. Five of the mines (Gregory, Alta, Bertha, Nellie Grant, and Corbin Flats) have been reclaimed in recent years, and correspondingly the associated sediment yield has decreased. The total pre-reclamation sediment load from abandoned mines was 1,098 tons/year, or 0.03 percent of the total Lake Helena sediment load; total post reclamation sediment load was 456 tons/yr, or 0.01 percent of total Lake Helena sediment load. Watershed wide, reclamation activities reduced abandoned mine related sediment yield by 642 ton/year, or 59 percent.

Sediment and nutrient loads were added to the appropriate watershed as described in Table 21. Nutrient loads were derived by applying the sediment nutrient concentrations discussed in Section 2.3.1.

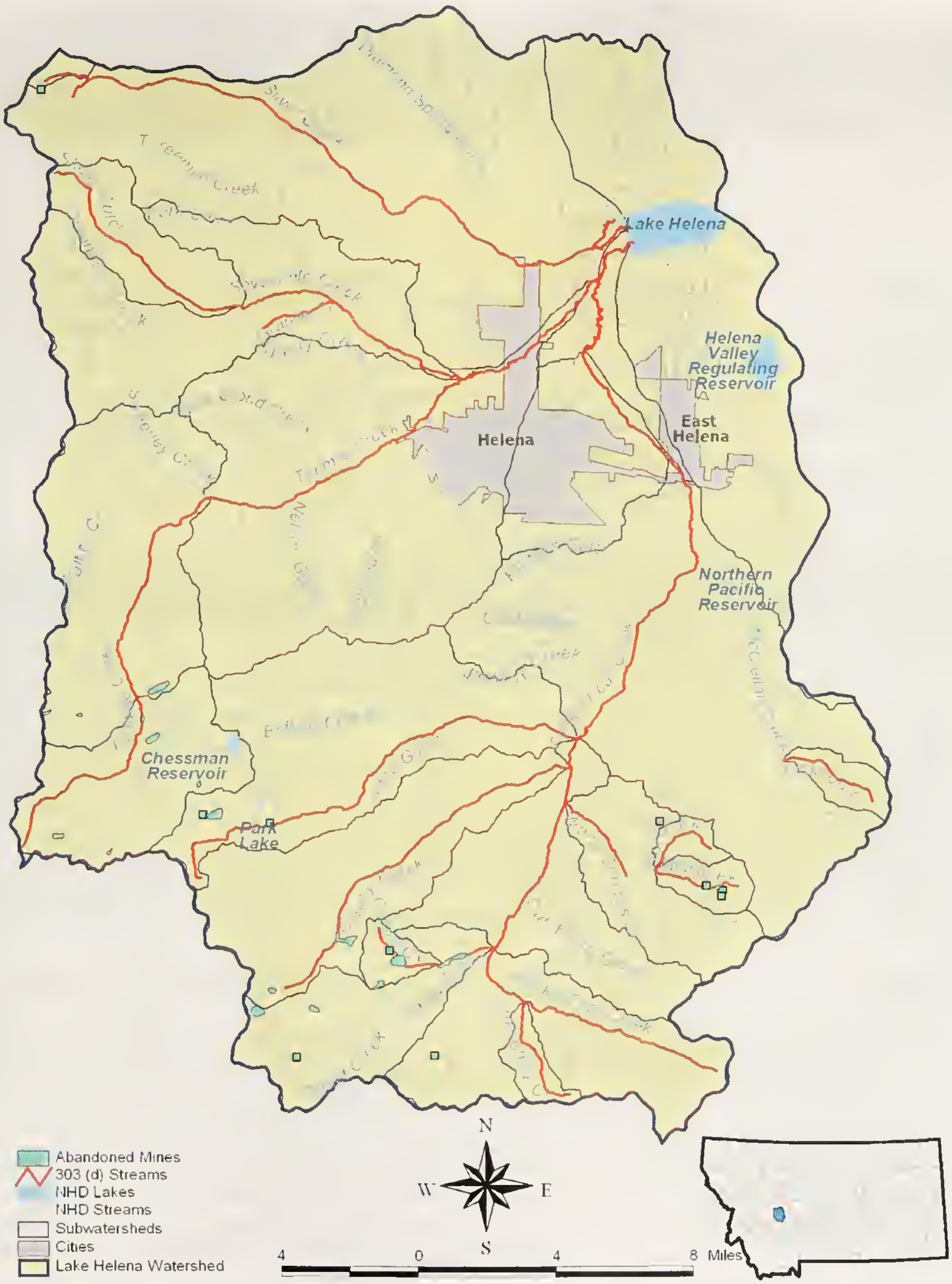


Figure 9. Location of Sediment-Producing Abandoned Mines in the Lake Helena Watershed

Table 19. Sediment Loads from Abandoned Mine Sites

Mine	Watershed	Total Sediment Producing Area (ft^2)	Pre-reclamation Sediment Load (mt/yr)	Post-reclamation Sediment Load (mt/yr)
Crawley Camp	Clancy Creek	No data	No data	No data
Gregory	Clancy Creek	77,235	32.8	0.0
Alta	Corbin Creek	39,000	16.1	16.1
Bertha	Corbin Creek	12,510	4.4	0.06
Black Jack Mine	Corbin Creek	11,769	4.6	N/A
Nellie Grant	Lump Gulch	5,040	1.0	0.01
Frohner Mine And Mill	Lump Gulch	87,120	44.1	N/A
Yama Group Mine	Lump Gulch	33,750	6.2	N/A
Middle Fork Warm Springs	Middle Fork Warm Springs	27,300	8.8	N/A
Solar Silver	Middle Fork Warm Springs	12,000	4.9	N/A
Newburgh Mine / Fleming Mine	Middle Fork Warm Springs	205,921	81.1	N/A
Warm Springs Tailings Adit	Middle Fork Warm Springs	369,453	98.7	N/A
White Pine Mine	Middle Fork Warm Springs	70,639	31.9	N/A
Armstrong Mine	Middle Tenmile Creek	46,475	13.8	N/A
Beatrice	Middle Tenmile Creek	7,695	2.3	N/A
Upper Valley Forge	Middle Tenmile Creek	7,590	2.2	N/A
Copper Gulch	Prickly Pear above Spring Creek	19,602	3.9	N/A
Bluebird	Spring Creek	8,7915	47.0	N/A
Corbin Flats	Spring Creek	1,742,400	587.9	0.0
Washington	Spring Creek	61,440	31.5	N/A
Salvai / Mt Washington Mine	Spring Creek	32,065	10.9	N/A
Monitor Creek Tailings	Upper Tenmile Creek	10,500	5.3	N/A
National Extension	Upper Tenmile Creek	12,000	6.1	N/A
Peter	Upper Tenmile Creek	1,150	0.6	N/A
Red Mountain	Upper Tenmile Creek	15,675	6.2	N/A
Red Water	Upper Tenmile Creek	4,500	2.3	N/A
Valley Forge/Susie	Upper Tenmile Creek	26,700	10.4	N/A
Woodrow Wilson	Upper Tenmile Creek	600	0.3	N/A
Badger	Warm Springs Creek	43,877	19.7	N/A

Table 20. Sediment Loads from Abandoned Mine Sites by Sub-Watershed

Sub-watershed	Pre-reclamation Delivered Sediment Load (mt/yr)	Post-reclamation Delivered Sediment Load (mt/yr)	Reduction in Sediment Load from reclamation activities (%)
Clancy Creek	32.8	0.0	100%
Corbin Creek	25.1	4.7	81.3%
Spring Creek	677.4	89.5	86.8%
Lump Gulch	51.3	50.3	1.9%
Middle Fork Warm Springs	225.4	N/A	0.0%
Warm Springs Creek	19.7	N/A	0.0%
Prickly Pear above Spring Creek	3.9	N/A	0.0%
Silver Creek	12.5	N/A	0.0%
Middle Tenmile Creek	18.3	N/A	0.0%
Upper Tenmile Creek	31.2	N/A	0.0%
Total	1,098	N/A	0.0%

Table 21. Sediment and Nutrient Loads from Abandoned Mines in the Lake Helena Watershed

Subwatershed	Delivered Sediment Load (mt/yr)	Total Nitrogen Load (mt/yr)	Total Phosphorus Load (mt/yr)
Corbin Creek	20.78	0.06	0.009
Lump Gulch	50.29	0.15	0.022
Middle Fork Warm Springs	151.27	0.45	0.067
Middle Tenmile Creek	18.30	0.05	0.008
Prickly Pear above Spring Creek	3.94	0.01	0.002
Silver Creek	12.53	0.04	0.006
Spring Creek	89.41	0.27	0.039
Upper Tenmile Creek	31.21	0.09	0.014
Warm Springs Creek	19.74	0.06	0.009

2.4.4 Loads from the Helena Valley Irrigation District

The GWLF model calculates nutrient loads resulting from precipitation induced runoff and erosion and does not consider any water or loading inputs from irrigation. Irrigation loading is therefore considered separately in the model. The Helena Valley Irrigation District provides approximately 350 cfs of water pumped from the Missouri River to the Lake Helena Watershed from mid-April through September each year (Jim Foster, Helena Valley Irrigation District, personal communications, October 6, 2004). A water balance based on weir measurements of canal and drain flows, crop water use, and evaporation from the open conduits was used to apportion flows into groundwater recharge and drain overflow fractions. The results are presented in Table 22 for a typical water year (2003).

Nutrient loads were estimated by applying appropriate concentrations to each source of flow from the irrigation district. Groundwater-recharge nutrient concentrations were based on suggested GWLF values for primarily agricultural watersheds: 0.71 mg-N/L and 0.104 mg-P/L. The nutrient concentrations in overflow drains were estimated by averaging values observed in three overflow drains during the summer of 2004 (0.71 mg-N/L and 0.037 mg-P/L). Resulting loads are 52 metric tons of total nitrogen and 6.6 metric tons of total phosphorus for 2003.

Table 22. Water Balance for the Helena Valley Irrigation District for 2003

Month	Groundwater Recharge (cfs)	Drain Overflow (cfs)	Evaporation (cfs)	Total Flow to Lake Helena (cfs)
April	25.0	56.0	0.25	80.75
May	36.5	39.5	0.39	75.61
June	178.0	41.0	0.45	218.55
July	200.3	29.7	0.63	229.37
August	210.9	51.1	0.53	261.47
September	129.7	34.3	0.31	163.69

Detailed water balance data were not available for the other modeling years. However, the Bureau of Reclamation provided water supply records for the years 1993 through 1996, 1999 through 2001, and 2003. A regression of net supply versus annual precipitation allowed for an estimation of net supply for years that records are not available. The estimated or observed net supply was then compared with that of 2003 to scale loads and flow volumes from the irrigation district. Table 23 shows the flows and loads for each modeling year.

Table 23. Additional Flow Volumes and Loads from the Helena Valley Irrigation District

Year	Scale Factor	Flow (MG)	TN (mt)	TP (mt)
1993	0.878	17,160	45.6	5.78
1994	0.988	19,311	51.3	6.51
1995	0.893	17,459	46.4	5.88
1996	1.053	20,572	54.7	6.93
1997	1.076	21,039	55.9	7.09
1998	1.130	22,092	58.7	7.45
1999	1.117	21,834	58.0	7.36
2000	1.130	22,082	58.7	7.44
2001	1.100	21,505	57.2	7.25
2002	1.164	22,755	60.5	7.67
2003	1.000	19,546	52.0	6.59

2.4.5 City of Helena Stormwater System

The City of Helena currently has a stormwater drainage system that eventually drains into several tributaries of the Lake Helena watershed. The City has applied for a permit under the Small Municipal Separate Storm Sewer System (MS4), but at the time of this report, the permit has not yet been granted. A detailed description of the system is provided in Appendix E and Appendix J.

2.4.6 Sewer System Expansion – Hypothetical Scenario

The City of Helena provides sewer service to areas in the Tenmile and Prickly Pear Creek watersheds. The City of East Helena also provides sewer service to portions of the Prickly Pear Creek watershed as well as the overland flow subwatershed. The existing sewer area covers approximately 15.8 square miles. Two hypothetical sewer system expansion scenarios were created to illustrate the impacts of sewer expansion. The first scenario (Scenario 1) assumes a 5.3 sq. mi. annexation area adjacent to existing sewer infrastructure. The second scenario (Scenario 2) assumes an additional 15.9 sq. mi. area where there is a fairly high density of subdivisions on septic systems. Figure 10 shows the areas currently served by sewer and the two hypothetical expansion areas.

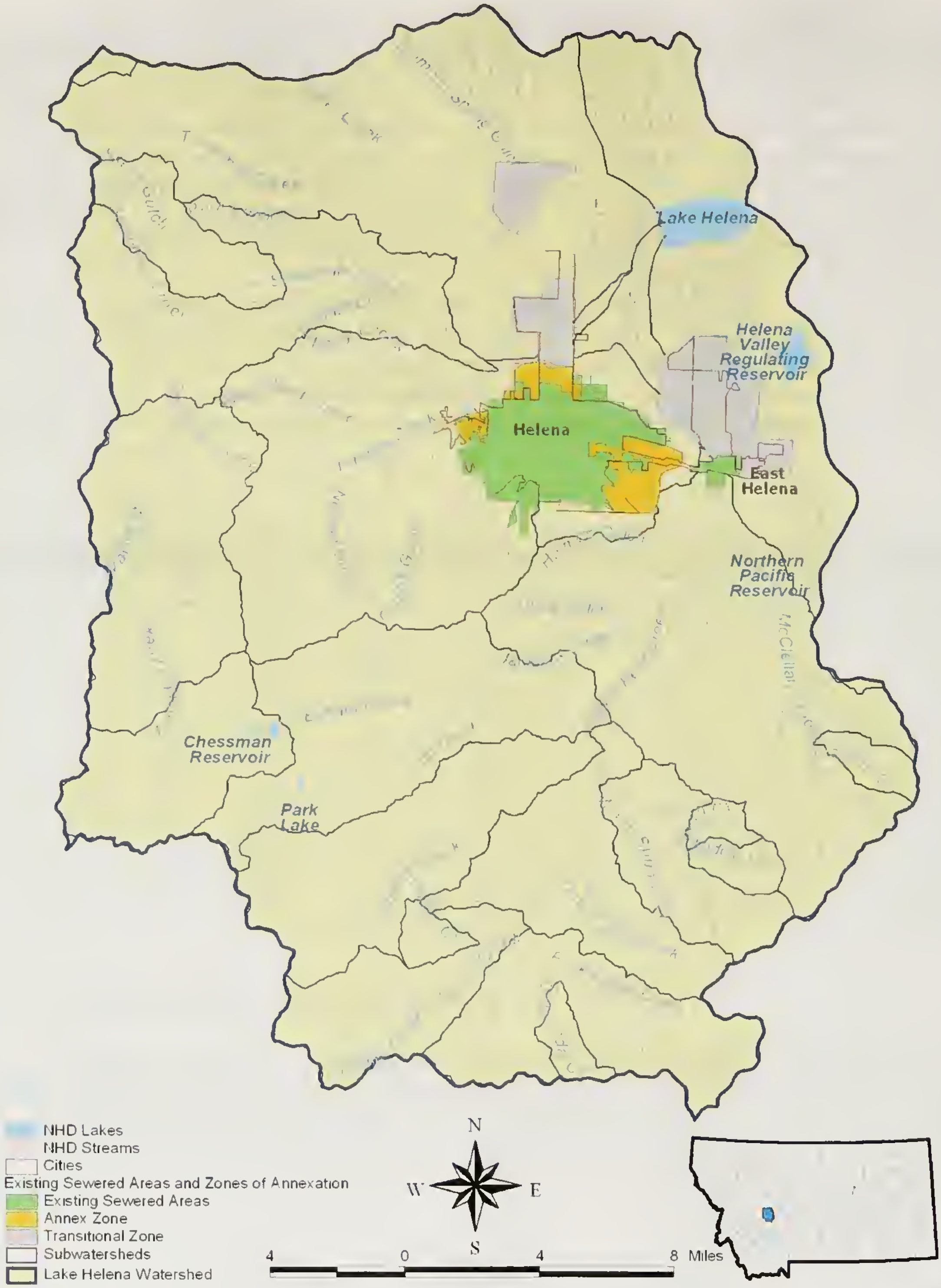


Figure 10. Sewer Service and Hypothetical Sewer System Expansion Zones in the Lake Helena Watershed

The GWLF model was used to estimate the potential impacts of sewer system expansion on total nitrogen and total phosphorus loading in each watershed. Table 24 and Table 25 show the simulation results. Scenario 1 would replace a total of 466 septic systems serving approximately 1,165 people and Scenario 2 would replace an additional 3,718 septic systems serving approximately 9,295 people.

The predicted net impact (i.e., at the Lake Helena watershed scale) of the hypothetical annexations is a decrease in nitrogen loads (-24%) and an increase in phosphorus loads (30%). Note that these values are based on the assumption that 7 percent of septic systems in the annexation areas are currently failing. Due to the smaller lot sizes in the City limits, the failure rate in this area is likely higher, and annexation may provide more reduction than assumed here. Also, estimated increases in loading from the City of Helena WWTP are based on current average plant effluent nutrient concentrations (7.7 mg-N/L and 5.0 mg-P/L). Enhanced WWTP treatment efficiency could improve the results substantially.

For Demonstration Purposes Only

It should be noted that this analysis of sewer system expansion has been conducted and presented for demonstration purposes only. It may not reflect details about specific expansion projects that may be pursued by the Cities of Helena or East Helena as well as the surrounding communities. However, it has been presented to demonstrate that the resulting water quality impacts of sewer system expansion may not be as expected, intuitively (i.e., they may not necessarily result in improved water quality). Future sewer system expansion projects should be accompanied by a water quality impact analysis conducted at the watershed scale, such that the overall affects (positive or negative) can be viewed in the proper context.

Table 24. Comparison of Cumulative Nitrogen Loading Under Two Hypothetical Annexation Scenarios

Watershed Component	Current Nitrogen Load mt/yr	Nitrogen Load Scenario 1 mt/yr	Net Percent Change	Nitrogen Load Scenarios 1 and 2 Combined mt/yr	Net Percent Change
Tenmile Creek: Septic Systems	16.8	12.7	-24.3%	11.3	-32.9%
Prickly Pear Creek: Septic Systems	33.6	28.8	-14.3%	25.5	-24.2%
Silver Creek: Septic Systems	36.9	36.9	0.0%	17.5	-52.7%
Overland Flow: Septic Systems	21.5	21.5	0.0%	6.2	-71.4%
WWTPs	36.5	37.8	3.6%	48.2	32.1%
Entire Lake Helena Watershed: Septic Systems and WWTP	128.6	125.1	-2.7%	97.3	-24.3%

Table 25. Comparison of Cumulative Phosphorus Loading Under Two Hypothetical Annexation Scenarios

Watershed Component	Current Phosphorus Load mt/yr	Phosphorus Load Scenario 1 mt/yr	Net Percent Change	Phosphorus Load Scenarios 1 and 2 Combined mt/yr	Net Percent Change
Tenmile Creek: Septic Systems	0.2	0.1	-24.3%	0.1	-32.9%
Prickly Pear Creek: Septic Systems	0.3	0.3	-14.3%	0.2	-24.2%
Silver Creek: Septic Systems	0.3	0.3	0.0%	0.2	-52.7%
Overland Flow: Septic Systems	0.2	0.2	0.0%	0.1	-71.4%
WWTPs	13.6	14.1	3.9%	18.3	34.7%
Entire Lake Helena Watershed: Septic Systems and WWTP	14.5	14.9	3.3%	18.8	29.9%

2.5 Summary of Pollutant Loading Sources

The GWLF modeling and additional analyses incorporate all known point and nonpoint sources of pollutant loading in the watershed. Table 26 summarizes each source category and the assumptions used to estimate pollutant loading.

Table 26.Summary of Pollutant Loading Sources in the Lake Helena Watershed

Source Category	Source	Summary/Description/Assumptions
Anthropogenic Nonpoint Sources	Timber Harvest	To account for harvesting activities in the watershed, forest was modeled by GWLF in one of three categories: (1) clear-cut, (2) regrowth, or (3) full growth condition. Forestland in the Lake Helena Watershed is owned by private land owners, the Bureau of Reclamation, Department of Natural Resources, Bureau of Land Management, and the Helena National Forest. Databases were obtained from each agency to estimate average harvest acreages. Harvest data on private lands was not available, so a continuous 90-yr harvesting cycle (Stuart, 2004) was assumed. To estimate the area of regrowth on private lands, a 5 year regrowth period (to re-establish full growth ground cover) was assumed. The curve numbers, cover factors, and nutrient runoff concentrations for each silvicultural land use category vary from typical forestland as described in Table 5, Table 7, and Table 9.
	Unpaved Roads	Road areas and corresponding road surface materials in the watershed were distinguished based on GIS data layers acquired from Lewis and Clark and Jefferson Counties and the Helena National Forest. The road polylines were converted into areas based on average widths from field data collected in 2005. Unpaved roads were buffered to a total width of 22 feet. The curve numbers, cover factors, and nutrient runoff concentrations of unpaved roads are described in Table 5, Table 7, and Table 9.
	Non-system Roads	Non-system roads are those built for recreational purposes (dirt bikes, four wheelers, etc.) and are not built to approved specifications. Road slope is assumed to follow the land gradient rather than incorporate switch-backs. Ditches and cross drains are not present. In the Helena National Forest, non-system roads were estimated to comprise an additional 4.6 percent of the area of unpaved roads (Stuart, 2004). This value was extrapolated to the entire Lake Helena Watershed where unpaved roads are present. The curve numbers, cover factors, and nutrient runoff concentrations of non-system roads are described in Table 5, Table 7, and Table 9.
	Paved Roads	Road areas and corresponding road surface materials in the watershed were distinguished based on GIS data layers acquired from Lewis and Clark and Jefferson Counties and the Helena National Forest. The road polylines were converted into areas based on average widths from field data collected in 2005. Paved roads were buffered to a total width of 26 feet. The curve numbers, cover factors, and nutrient runoff concentrations of paved roads are described in Table 5, Table 7, and Table 9.
	Active Mines and Quarries	Identification of active mines and quarries is based on the Multi-Resolution Land Characterization (MRLC) dataset acquired between 1991 and 1993. Updates to the data based on 2004 high-resolution color orthophotos of the Helena Valley were made to reflect current conditions in the Lake Helena watershed. Only areas draining offsite, based on topographic data, were included in the pollutant loading estimates. The curve numbers, cover factors, and nutrient runoff concentrations for active mines and quarries are described in Table 5, Table 7, and Table 9.
	Abandoned Mines	Sediment loads associated with abandoned mining were calculated for sites throughout the Lake Helena watershed. Potential sediment source locations were delineated from the High Priority Abandoned Hardrock Mine Sites, and Abandoned and Inactive Mines of Montana, as well as the National Hydrography Dataset GIS data layers. Potential sediment source delineation criteria were as follows: mine sites within 300 feet of a stream, or mines within 1,000 feet of a stream in areas where slopes are greater than 30 percent. This GIS exercise generated 223 mines deemed to be potential sediment sources. These mines were cross-referenced with Montana Bureau of Mines and Geology (MBMG) reports, and the Montana State Bureau of Abandoned Mines. Available MBMG documents reported that 12 of the Abandoned-Inactive mines were probable sediment sources. Additionally, records of High Priority Abandoned Hardrock Mine Sites from the Montana State Bureau of Abandoned Mines indicated that 18 additional mine sites were probable sediment sources. Area-based sediment loads for waste rock piles were obtained from a report produced by CDM, for USEPA, for use in the Upper Tenmile Creek Mining Area Superfund site. CDM used RUSLE version 1.06 to generate a sediment yield of 27 tons/acre/year from nose slopes, and 16 tons/acre/year from side slopes of waste rock piles in loamy-sand textured soil. Sediment delivery ratios were generated based on methodology described in *Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands* (Toy and Galetovic, 1999). Five of the High Priority Abandoned Mine sites were reported to be reclaimed. The level of reclamation, and associated reduction in sediment production was assessed at each of the five sites. Sediment and nutrient loads from abandoned mines are summarized in Table 18, Table 19, and Table 20.
	Agriculture	Identification of agricultural areas (pasture/hay, small grains, row crops, fallow fields) is based on the Multi-Resolution Land Characterization (MRLC) dataset acquired between 1991 and 1993. Updates to the data based on 2004 high-resolution color orthophotos of the Helena Valley were made to reflect current conditions in the Lake Helena watershed. The curve numbers, cover factors, and nutrient runoff concentrations for each agricultural land use are described in Table 5, Table 7, and Table 9.
	Urban Areas	Identification of urban areas (low and high intensity residential, commercial, industrial, transportation, etc.) is based on the Multi-Resolution Land Characterization (MRLC) dataset acquired between 1991 and 1993. Updates to the original data and refinements of land use categories were made to reflect current conditions in the Lake Helena watershed based on 2004 high-resolution color orthophotos of the Helena Valley. Additionally, a new class of low-intensity residential development was added to reflect the low-density style of land development in the more rural areas of the Lake Helena Watershed. The curve numbers, cover factors, and nutrient build-up washoff rates for each urban land use are described in Table 5, Table 7, and Table 9.

Table 26.Summary of Pollutant Loading Sources in the Lake Helena Watershed

Source Category	Source	Summary/Description/Assumptions
	Anthropogenic Streambank Erosion	Bank Erosion Hazard Index (BEHI) assessments were conducted on intra-segment reaches of streams in the Lake Helena watershed to assess streambank erosion. Results from sampled reaches were averaged and extrapolated to the full perennial stream length within a listed stream segment's watershed. To determine annual sediment load from eroding streambanks in each BEHI category (low, moderate, high, severe), bank retreat rates developed by Rosgen (2001) were used (Table 16). The rate of erosion was then multiplied by the area of eroding bank to obtain a volume of sediment per year, and then multiplied by the average bulk sediment density to estimate mass. Additionally, the total sediment load related to eroding streambanks was allocated between naturally occurring and anthropogenically induced erosion. This allocation was determined through observations during field reconnaissance and by aerial photo assessments. Land uses adjacent to, or in some cases upstream from, eroding streambanks were surveyed and correlated to natural or anthropogenic erosion conditions.
	Helena Valley Irrigation System	The Helena Valley Irrigation District provides approximately 350 cfs of water pumped from the Missouri River to the Lake Helena Watershed from mid-April through September each year (Foster, 2004). A water balance for year 2003 based on weir measurements of canal and drain flows, crop water use, and evaporation from the open conduits was used to apportion flows into groundwater recharge and drain overflow fractions during a typical water year. Nutrient loads were estimated by applying appropriate concentrations to each source of flow from the irrigation district. Groundwater-recharge nutrient concentrations were based on suggested GWLF values for primarily agricultural watersheds: 0.71 mg-N/L and 0.104 mg-P/L. The nutrient concentrations in overflow drains were estimated by averaging values observed in three overflow drains during the summer of 2004 (0.71 mg-N/L and 0.037 mg-P/L). Detailed water balance data were not available for the other modeling years. However, the Bureau of Reclamation provided water supply records for the years 1993 through 1996, 1999, 2000, 2001, and 2003. A regression of net supply and annual precipitation allowed for an estimation of net supply for years that records were not available.
	Septic Systems	The population served by septic systems in the Lake Helena watershed (Table 12) is based on the Lewis and Clark County GIS database of permitted systems, the ratio of permitted systems to total systems reported in the Lewis and Clark County Inventory of Onsite Wastewater Treatment Systems (2001), the ratio of total systems to wells, and well data collected in Lewis and Clark and Jefferson Counties. Based on national average failure rates, it was assumed that 7 percent of all systems were failing such that tank effluent bypassed treatment by soil adsorption and plant uptake. Tank effluent loading rates and plant uptake rates are shown in Table 13.
Natural Nonpoint Sources	Fullgrowth Forest	Identification of forest areas (deciduous, evergreen, and mixed) is based on the Multi-Resolution Land Characterization (MRLC) acquired between 1991 and 1993. Updates to the original data and refinements of land use categories were made to reflect current conditions in the Lake Helena watershed based on 2004 high-resolution color orthophotos of the Helena Valley. The curve numbers, cover factors, and nutrient concentrations for each forest land use are described in Table 5, Table 7, and Table 9.
	Wetlands	Identification of wetland areas (woody and herbaceous) is based on the Multi-Resolution Land Characterization (MRLC) acquired between 1991 and 1993. Updates to the original data and refinements of land use categories were made to reflect current conditions in the Lake Helena watershed based on 2004 high-resolution color orthophotos of the Helena Valley. The curve numbers, cover factors, and nutrient concentrations for each wetland land use are described in Table 5, Table 7, and Table 9.
	Shrubland	Identification of shrubland areas is based on the Multi-Resolution Land Characterization (MRLC) acquired between 1991 and 1993. Updates to the original data and refinements of land use categories were made to reflect current conditions in the Lake Helena watershed based on 2004 high-resolution color orthophotos of the Helena Valley. The curve numbers, cover factors, and nutrient concentrations for shrubland are described in Table 5, Table 7, and Table 9.
	Grassland	Identification of grassland areas is based on the Multi-Resolution Land Characterization (MRLC) acquired between 1991 and 1993. Updates to the original data and refinements of land use categories were made to reflect current conditions in the Lake Helena watershed based on 2004 high-resolution color orthophotos of the Helena Valley. The curve numbers, cover factors, and nutrient concentrations for grassland are described in Table 5, Table 7, and Table 9.
	Natural Streambank Erosion	Bank Erosion Hazard Index (BEHI) assessments were conducted on intra-segment reaches of streams in the Lake Helena watershed to assess streambank erosion. Results from sampled reaches were averaged and extrapolated to the full perennial stream length within a listed stream segment's watershed. To determine annual sediment load from eroding streambanks in each BEHI category (low, moderate, high, severe), bank retreat rates developed by Rosgen (2001) were used (Table 16). The rate of erosion was then multiplied by the area of eroding bank to obtain a volume of sediment per year, and then multiplied by the average bulk sediment density to estimate mass. Additionally, the total sediment load related to eroding streambanks was allocated between naturally occurring and anthropogenically induced erosion. This allocation was determined through observations during field reconnaissance and by aerial photo assessments. Land uses adjacent to, or in some cases upstream from, eroding streambanks were surveyed and correlated to natural or anthropogenic erosion conditions.

Table 26.Summary of Pollutant Loading Sources in the Lake Helena Watershed

Source Category	Source	Summary/Description/Assumptions
	Groundwater	The GWLF model has three subsurface zones: a shallow unsaturated zone, a shallow saturated zone, and a deep aquifer zone. Behavior of the second two stores is controlled by a groundwater recession and a deep seepage coefficient. The recession coefficient was set to 0.01 per day and the deep seepage coefficient to 0, based on several calibration runs of the model. Groundwater nutrient concentrations were based on baseflow measurements reported in the GWLF manual for various levels of forested and agriculturally developed watersheds. Completely forested watersheds have values of 0.07 mg-N/L and 0.012 mg-P/L. Primarily agricultural watersheds have values of 0.71 mg-N/L and 0.104 mg-P/L. Intermediary values are also reported. Values for each subwatershed were assigned based on the percent forest and agricultural land use in the watershed.
Anthropogenic Point Sources	City of Helena: post-upgrades	The City of Helena wastewater treatment facility is located in the northeast section of Helena, Montana in the Prickly Pear Creek watershed. Prior to 2001, the facility operated a secondary treatment bio-tower system. In June of 2001, an advanced secondary treatment wastewater system with nitrification/denitrification went online. Under Montana DEQ Permit MT0022641, the facility has a permitted discharge of 6.2 MGD, and permitted ammonia limits that vary by month. Discharge from the Helena treatment plant enters an unnamed irrigation ditch that originates near the facility and eventually flows into Prickly Pear Creek. However, during the irrigation season (April-October), irrigators withdraw water from the ditch, and discharge flows from the plant rarely reach Prickly Pear Creek. Losses due to irrigation of wastewater were applied from April through October. The nitrate present in the irrigated effluent (5.32 mg/L average post-upgrade value reported in DMRs) is assumed to pass through the system. Ninety percent of phosphorus is assumed removed by the irrigated fields.
	East Helena: post-upgrades	The City of East Helena wastewater treatment facility is located approximately 0.5 miles north of the city in the Prickly Pear Creek watershed. Prior to 2003, the facility operated three partially mixed ponds with a designed retention time of 30 days. In 2003, the plant was renovated and now operates an advanced secondary treatment activated sludge system with nitrification. Under Montana DEQ Permit #MT0022560, the facility has a permitted discharge of 0.43 MGD, permitted TP load of 20 lb/day, and a permitted TN load of 80 lb/day. At the time of the permit application, the system served approximately 1,673 people from East Helena and the surrounding area. The average observed flow rate from January 2003 to July 2005 was 0.20 MGD, with an average TN concentration of 23.2 mg/L, an average TP concentration of 3.6 mg/L, and an average NO_2+NO_3 concentration of 14.3 mg/L. Ammonia concentrations were non-detectable for most sampling events (less than 0.1 mg/L). Prior to the plant upgrade, ammonia concentrations were much higher (average of 4.1 mg/L) and NO_2+NO_3 concentrations much lower (average of 1.0 mg/L). The current values reflect the facility's new nitrification system, which converts ammonia to nitrate and nitrite.
	Evergreen Nursing Home	The Evergreen Nursing Facility is located in Clancy, Montana in the Prickly Pear Creek watershed. The facility operates a secondary treatment activated sludge wastewater system. Under Montana DEQ Permit MT0023566, the facility has a permitted discharge of 15,000 GPD, and does not currently have permit limits for any species of nitrogen or phosphorus. Thirty-four occupants along with all support staff for the Evergreen Nursing facility are served by this system. The average observed flow rate from January 1998 to April 2005 was 6,876 GPD, with an average TN concentration of 11.9 mg/L, an average TP concentration of 2.9 mg/L, and an average NO_2+NO_3 concentration of 8.4 mg/L.
	Treasure State Acres Subdivision	The Treasure State Acres subdivision is located approximately 1.5 miles north of the city of Helena in the Prickly Pear Creek watershed. Montana DEQ does not require a permit from this facility. There is currently a wastewater treatment system consisting of two storage ponds treating 0.1 MGD. Effluent is applied to cropland. There is insufficient pond storage capacity for the population served (Damschen & Associates, 1998), so full treatment is unlikely. Applied concentrations are based on USEPA (1997) values for post-sedimentation values, not stabilization values, of 25 mg-N/L and 8 mg-P/L (Table 14). The nitrate present in irrigated effluent is assumed to pass through the system, and the USEPA guidance suggests a value of 2 percent of the total nitrogen concentration to estimate nitrate concentrations in primary or secondary treatment effluent. Ninety percent of phosphorus is assumed removed by the irrigated fields.
	Tenmile and Pleasant Valley Subdivisions	The Tenmile and Pleasant Valley subdivisions are located approximately 1.5 miles north of the City of Helena (Helena Valley) in the Prickly Pear Creek subwatershed, and just north of the Treasure State Acres subdivision. Tenmile and Pleasant Valley are served by a 0.09 MGD wastewater treatment system consisting of four ponds designed for total retention with disposal via evaporation. Montana DEQ does not require a permit from this facility. Though current wastewater flows should fill all four ponds, only one pond currently fills. Water balance calculations performed by the authors of the Helena Valley Facility Plan conclude that excessive seepage is occurring from the ponds (Damschen & Associates, 1998). Because of this, Montana DEQ is currently pursuing enforcement action against the subdivision (Jim Lloyd, Personal Communications, September 27, 2005). It is assumed that 25 percent of the flow is discharged to the subsurface with concentrations typical of "stabilization pond effluent" and that 75 percent of the effluent is discharged to the subsurface at "after sedimentation" concentrations (Table 14). Phosphorus adsorption is assumed to uptake 90 percent of total phosphorus; however, all inorganic nitrogen is assumed to pass through to groundwater.
	Mountain View Law Enforcement Academy	The Mountain View Law Enforcement Academy is located approximately 3.5 miles north of the city of Helena in the subwatershed draining directly to Lake Helena. The academy currently possesses two small, facultative treatment ponds that treat 0.007 MGD. Montana DEQ does not require a permit from this facility. Effluent discharge occurs by evaporation, seepage, and direct discharge to Prickly Pear Creek. There is no evidence that the system is not operating as designed, so it is assumed that 100 percent of the flow discharges to Prickly Pear Creek with stabilization pond effluent values (Table 14). No surface area information or actual flow measurements are available to account for evaporative losses.

Table 26.Summary of Pollutant Loading Sources in the Lake Helena Watershed

Source Category	Source	Summary/Description/Assumptions
	Eastgate Subdivision	The Eastgate Subdivision Homeowners Association is located approximately one mile northeast of the city of East Helena. The subdivision currently operates a wastewater treatment system consisting of two mechanically aerated ponds that are designed to treat 0.15 million gallons per day (MGD). Montana DEQ does not require a permit for this facility. Final effluent is disposed via irrigation to cropland, and this system is currently in compliance and meeting design specifications. The concentrations reported for total nitrogen and total phosphorus after stabilization (USEPA, 1997) are 14.5 mg-N/L and 5 mg-P/L (Table 14). While no groundwater monitoring data are available, the nitrate present in irrigated effluent is assumed to pass through the system, and the USEPA guidance suggests a value of 2 percent of the total nitrogen concentration to estimate nitrate concentrations in primary or secondary treatment effluent. Ninety percent of phosphorus is assumed removed by the irrigated fields.
	Leisure Village Mobile Home Park	The Leisure Village Mobile Home Park is located approximately 1.5 miles northeast of the city of Helena in the subwatershed draining directly to Lake Helena. Four treatment/storage ponds receiving 0.1 MGD serve the Leisure Village Mobile Home Park. Montana DEQ does not require a permit from this facility. Only one pond currently fills, but waste flows are sufficient to fill all four ponds. It is assumed that 25 percent of the flow is discharged to the subsurface with concentrations typical of “stabilization pond effluent” and that 75 percent of the effluent is discharged to the subsurface at “after sedimentation” concentrations (Table 14). Phosphorus adsorption is assumed to uptake 90 percent of total phosphorus; however, all inorganic nitrogen is assumed to pass through to groundwater.
Total	Totals	All known point and non-point sources currently active in the Lake Helena watershed were included in the TMDLs. In general, MRLC data collected around 1992 were used to estimate the land use types in each watershed. Orthophotos of Helena Valley taken in 2004 were used to update the land use data to reflect current conditions. Road data were obtained from GIS data layers acquired from Lewis and Clark and Jefferson Counties and the Helena National Forest. Literature values were used for curve numbers, cover factors, and nutrient parameters for each land use. Septic system loading rates were based on GWLF default values for normal and failing systems and population estimates based on data collected in Lewis and Clark and Jefferson Counties. Separate loading analyses were performed for the Helena Valley Irrigation District, streambank erosion, abandoned mines, and centralized wastewater treatment systems.

2.6 GWLF Calibration

Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. Hydrologic calibration precedes water quality calibration because runoff is the transport mechanism by which nonpoint pollution occurs. In an ideal situation, calibration is an iterative procedure of parameter evaluation and refinement as a result of comparing simulated and observed values of interest and is based on several years of simulation to evaluate parameters under a variety of climatic conditions. Unfortunately, limited flow and water quality data were available to perform this sort of a calibration for the Lake Helena watershed. Therefore, default values were used for most modeling parameters with limited adjustment during the calibration process. A comparison of the simulated and observed data is presented below and the implications of the limited available data and calibration are described further in Section 5.0.

2.6.1 Hydrologic Calibration

The GWLF model predicts flow volumes from runoff at monthly intervals. Flows from the Helena Valley Irrigation District and wastewater treatment plants were added during post-processing. Simulated flows were compared to observed flows at USGS Gage 06061500 (Prickly Pear Creek near Clancy, MT) during model calibration. Daily flows reported from January 1980 through September 2002 were summed by month for comparison with the GWLF simulation. As shown in Figure 11 the period from 1980 to 2002 includes years with low, average, and high annual flows.

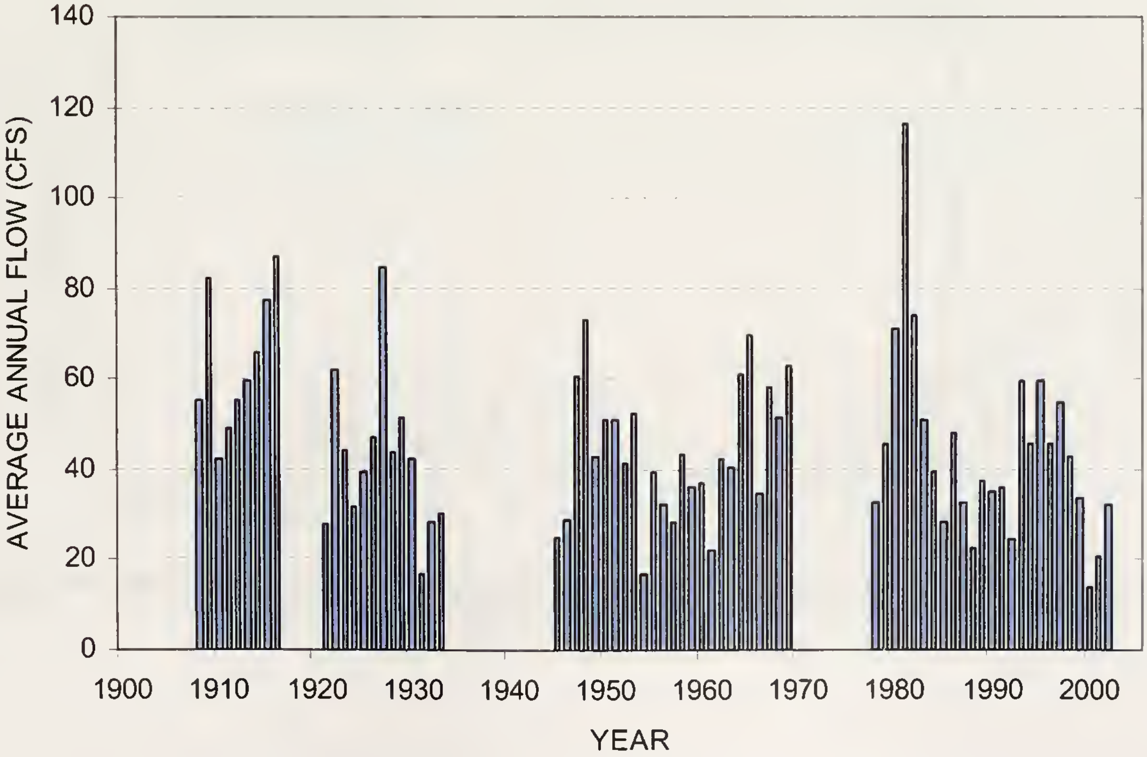


Figure 11. Average Annual Flows Over the Period of Record for Prickly Pear Creek Near Clancy (USGS Gage 06061500)

Figure 12 compares the monthly flow volumes observed at the gage to GWLF estimates and indicates that the model matches certain months better than others. In general the observed monthly flows appear to be less variable than the simulated monthly flows. This might be related to the use of only one weather station to represent precipitation throughout the watershed (see Section 2.2). Monthly flows are often over-estimated when high precipitation values (e.g., greater than 20 cm/month) are recorded at the Helena airport and are under-estimated when low precipitation values are recorded (e.g., less than 10 cm/month). Figure 12 also indicates that the model reasonably simulates runoff volumes during the typically wetter months of April through June. For example, Figure 13 compares the monthly flow volumes observed at the gage to GWLF estimates over a shorter time period (January 1998 through December 2000). GWLF matches the volume of the spring snowmelt period fairly well, although the timing is slightly late. Summer and fall flows are slightly over-estimated in 1998 and 1999 and under-estimated in 2000, possibly due to an inadequate representation in the model of flow withdrawals and other anthropogenic impacts.

Figure 14 displays the range of the monthly observed and simulated flows and also indicates greater variability in the simulated flows compared to the observed flows. The simulated maximum monthly flow is similar to the observed, although the minimum is considerably less.

Figure 15 compares the annual simulated and observed totals for the period 1980 to 2002 and indicates relatively close agreement for most years. The error in total stream flow for this period is 32 percent but only 20 percent if 1993 is excluded.

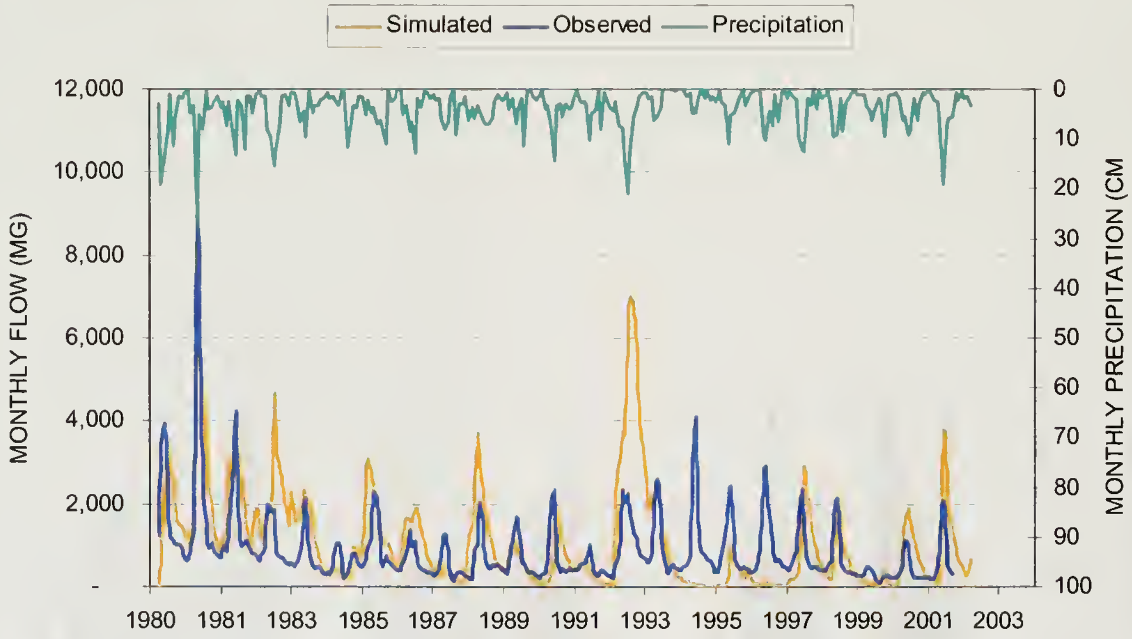


Figure 12. Comparison of Simulated and Observed Monthly Flow Volumes at USGS Gage 06061500, Along with Monthly Precipitation at the Helena Airport

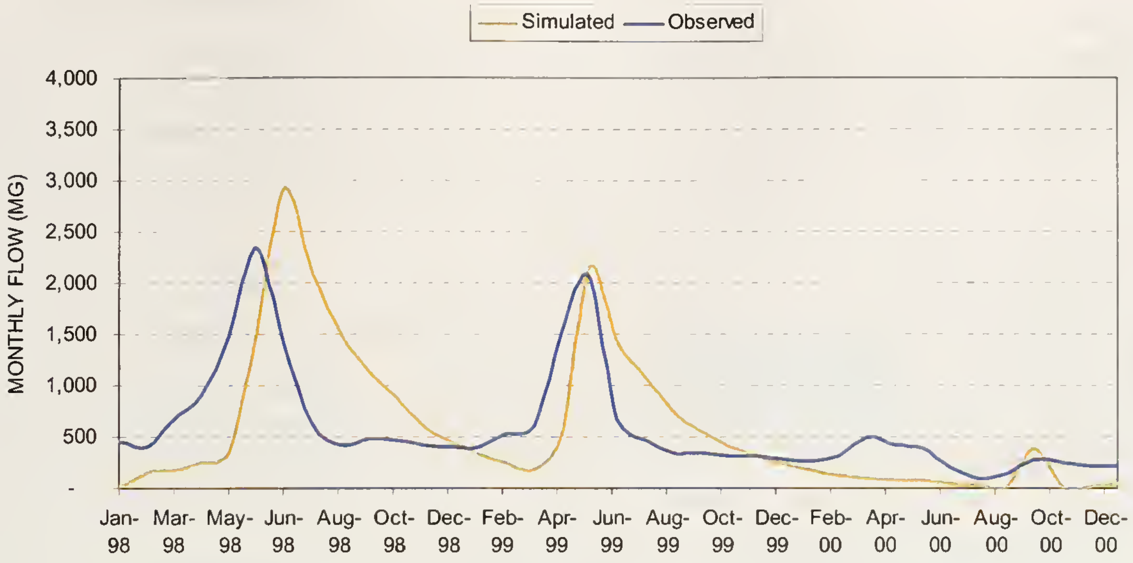


Figure 13. Comparison of Simulated and Observed Monthly Flow Volumes at USGS Gage 06061500 for the Period January 1, 1998 through December 31, 2000

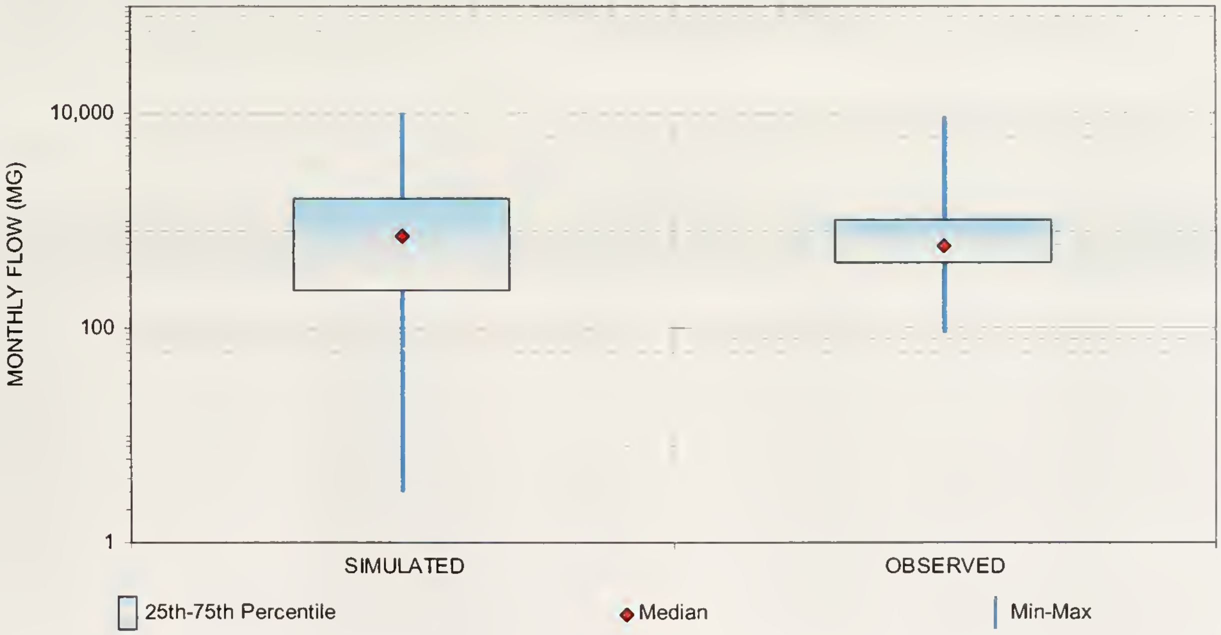


Figure 14. Range of Simulated and Observed Monthly Flows at USGS Gage 06061500 for the period 1980 to 2002

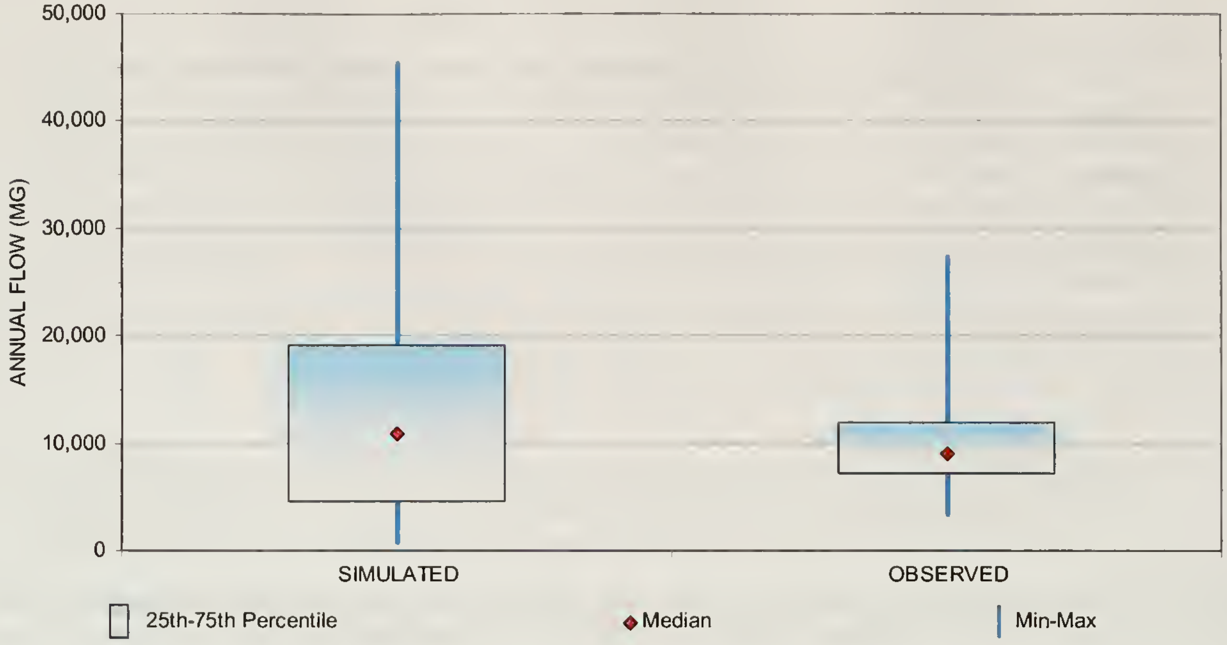


Figure 15. Comparison of Simulated and Observed Annual Flow Volumes at USGS Gage 06061500 for the Period 1980 to 2002

2.6.2 Nutrient Calibration

Two USGS gages were chosen for the comparison of simulated nutrient loads to represent the two major tributaries to Lake Helena: Tenmile Creek and Prickly Pear Creek. The USGS has not collected more than two water quality samples at any gage along Silver Creek with which to develop a meaningful comparison. Water quality data collected by other agencies in the watershed were not used because instantaneous flow measurements are required to extrapolate a daily load.

The USGS Gage along Tenmile Creek (Gage 06063000) is located in the "Tenmile above Prickly Pear Creek" GWLF subwatershed. The drainage area to the USGS gage is 96.5 square miles whereas the drainage area of the modeling subwatershed is 136.9 square miles. Very limited data (8 sampling events from 2002 and 2003) were available for comparison to simulated loads (Table 27). The average annual simulated load at the outlet of the modeling subwatershed was converted to a daily load and scaled down by the ratio of the drainage areas to estimate the simulated load at the gage. The minimum, average, and maximum daily observed and simulated loads are shown in Figure 16 (for total nitrogen) and Figure 17 (for phosphorus). In both cases the average simulated loads are greater than the average observed loads. There are several possible reasons for the difference including modeling assumptions used to simulate diversions in the Upper Tenmile reaches or the small number of sampling events (eight) used to generate the comparison. It should also be noted that the simulated loads are annual average loads from a twenty year model run converted to a daily load (tons/day) whereas the observed USGS loads are instantaneous loads converted to the same daily units. The observed and simulated loads are therefore not directly comparable and the observed loads might be biased due to only being collected during one season (typically summer) or one flow condition (typically low flows). Both 2002 and 2003 were relatively dry years and therefore it is reasonable to assume that long-term daily loading rates are greater than those represented by the limited sampling data.

Table 27. Observations of Stream Flow, Total Phosphorus, and Total Nitrogen at USGS Gage 06063000 on Tenmile Creek

Site Number	Date	Flow (cfs)	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)
06063000	4/17/02	8.8	0.029	0.434
06063000	5/28/02	97.0	0.043	0.362
06063000	7/29/02	1.1	0.019	0.352
06063000	10/9/02	0.4	0.009	0.286
06063000	3/13/03	1.0	0.210	1.058
06063000	5/27/03	164.0	0.059	0.350
06063000	7/23/03	0.5	0.022	0.668
06063000	12/4/03	0.5	0.008	0.331
	Average	34.2	0.050	0.480

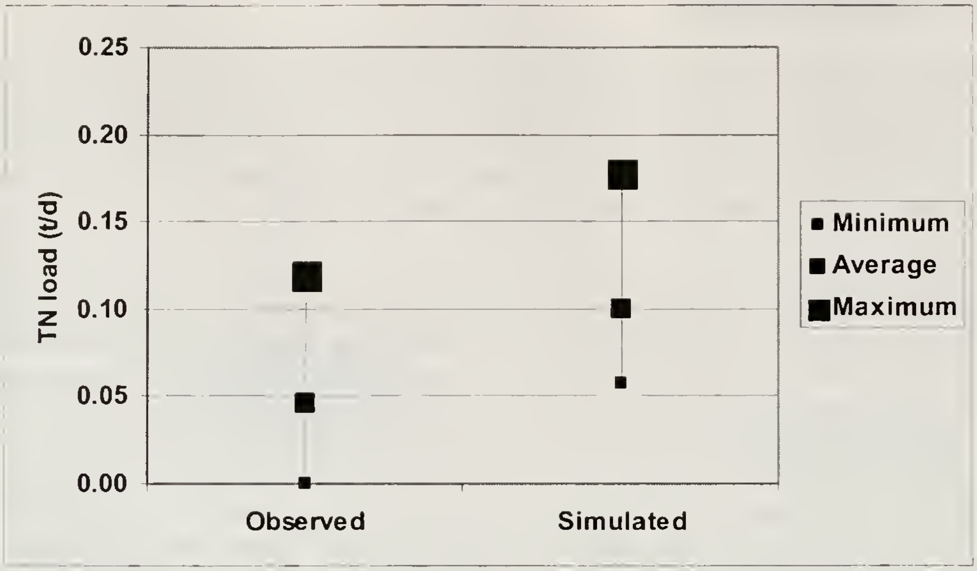


Figure 16. Comparison of Observed and Simulated Daily Total Nitrogen Load at USGS Gage 06063000 Along Tenmile Creek (Observed Loads Based on 8 Samples; Simulated Loads Based on Twenty Years of Model Output)

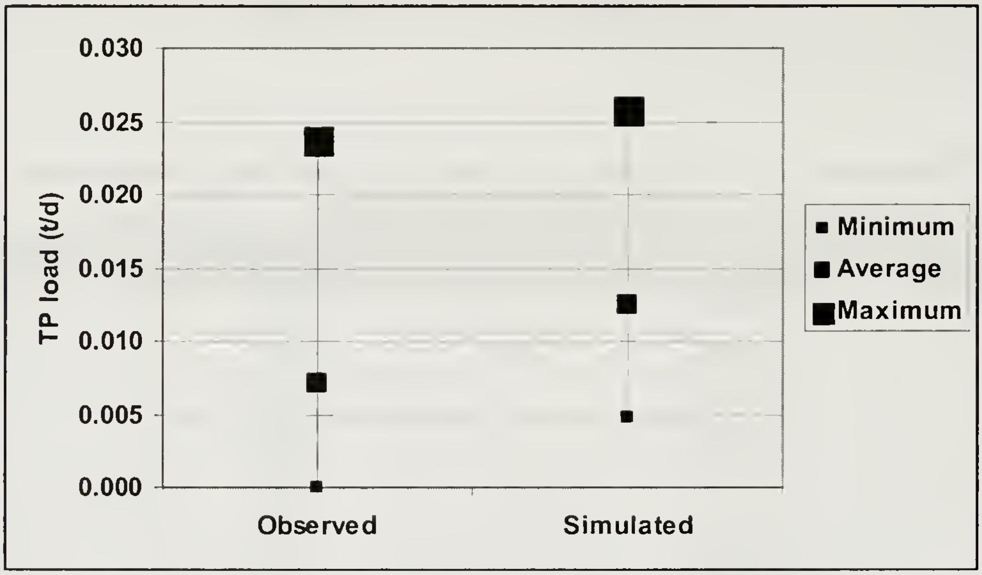


Figure 17. Comparison of Observed and Simulated Daily Total Phosphorus Load at USGS Gage 06063000 Along Tenmile Creek (Observed Loads Based on 8 Samples; Simulated Loads Based on Twenty Years of Model Output)

USGS Gage 06061500 was chosen to represent the loads for Prickly Pear Creek and 20 sampling events were available for the comparison (Table 28). The drainage area of this gage is 192 square miles, and it is located in the "Prickly Pear Creek above Wylie Drive" subwatershed. Simulated loads for this subwatershed represent a drainage area of 250 square miles so loads were scaled down for comparison with the gage data. Figure 18 shows the comparison of daily total nitrogen loads from observed instantaneous loads and simulated annual average loads. Figure 19 shows the same comparison for total phosphorus. At this gage, simulated total nitrogen loads and simulated total phosphorus loads are within the range observed at the gage with average simulated loads slightly greater than the observed loads. This could be due to model limitations or could be due to potential bias in the observed data as discussed above.

Table 28. Observations of Stream Flow, Total Phosphorus, and Total Nitrogen at USGS Gage 06061500 on Prickly Pear Creek

Site Number	Date	Stream flow (cfs)	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)
06061500	5/19/1999	71	0.075	0.479
06061500	5/25/1999	109	0.132	0.541
06061500	6/4/1999	201	0.128	0.570
06061500	8/18/1999	22	0.024	0.319
06061500	11/5/1999	17	0.013	0.251
06061500	3/21/2000	14	0.014	0.354
06061500	6/1/2000	33	0.040	0.381
06061500	8/7/2000	4.7	0.015	0.232
06061500	4/25/2001	35	0.039	0.435
06061500	5/16/2001	71	0.041	0.344
06061500	7/19/2001	32	0.021	0.274
06061500	8/22/2001	8	0.008	0.220
06061500	10/23/2001	12	0.006	0.211
06061500	4/5/2002	17	0.015	0.374
06061500	5/20/2002	82	0.124	0.787
06061500	7/29/2002	22	0.013	0.216
06061500	4/17/2003	43	0.024	0.325
06061500	5/20/2003	64	0.025	0.338
06061500	6/2/2003	98	0.045	0.429
06061500	7/22/2003	12	0.017	0.401
	Average	48	0.041	0.374

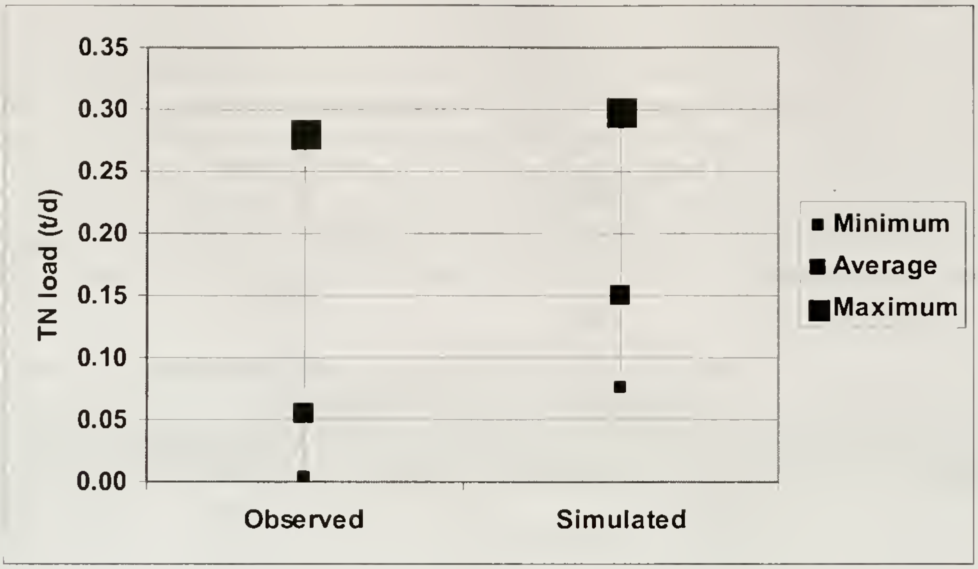


Figure 18. Comparison of Observed and Simulated Daily Total Nitrogen Load at USGS Gage 06061500 Along Prickly Pear Creek (Observed Loads Based on 20 Samples; Simulated Loads Based on Twenty Years of Model Output)

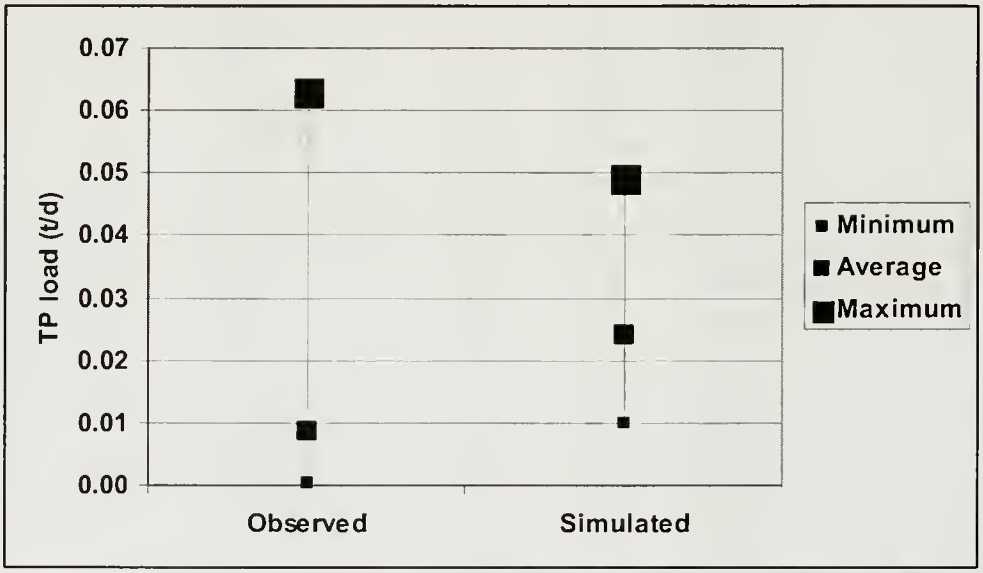


Figure 19. Comparison of Observed and Simulated Daily Total Phosphorus Load at USGS Gage 06061500 Along Prickly Pear Creek (Observed Loads Based on 20 Samples; Simulated Loads Based on Twenty Years of Model Output)

3.0 BATHTUB MODEL SETUP

The USACE BATHTUB model (Walker, 1987) was set up to simulate nutrient response in Lake Helena based on input from the GWLF model for the various scenarios. BATHTUB performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network, which accounts for pollutant transport and sedimentation. Eutrophication-related water quality conditions (e.g., phosphorus, nitrogen, chlorophyll *a*, and transparency) are predicted using empirical relationships previously developed and tested for reservoir applications (Walker, 1987). BATHTUB was determined to be appropriate because it addresses the parameters of concern and has been used previously for reservoir TMDL applications. The use of more sophisticated lake models was not warranted based on the very limited water quality data with which they could be calibrated.

3.1 Lake Morphology

The BATHTUB model requires basic lake morphometric data (Table 29) to assess residence time, net flow rate, and potential euphotic depth. Morphometric data are based on information provided by Montana DEQ (Mike Suplee, Montana DEQ, personal communications, November 10, 2004). Because the lake is fairly uniform and no ponding occurs along the downstream reaches of the tributaries, segmentation is not required.

Table 29. Lake Helena Morphology

Lake Volume (10^6 m^3)	13.45
Average Depth (m)	1.6
Surface area (km^2)	8.41

3.2 Atmospheric Deposition to Lake Helena

Atmospheric deposition can contribute a significant proportion of nitrogen loads directly to a lake surface, particularly when the ratio of watershed area to lake surface area is low. The Lake Helena watershed to lake area ratio is relatively high (192) so atmospheric deposition is not likely a major source of nutrient loading.

Total wet and dry nitrogen deposition rates to the lake surface (1.5 kg/ha) were based on CASTNET monitoring at Glacier National Park (GLR468) for 1997. Phosphorus deposition rates (primarily from wind blown dust) are generalized estimates (0.1 kg/ha).

3.3 Inorganic Nutrient Fractions

BATHTUB requires an estimate of inorganic nutrient fractions for all loads to the lake. The inorganic nutrient fractions for the watershed loads were approximated from the ratios of dissolved nutrient load to total nutrient load predicted by GWLF for each year. Atmospheric and groundwater recharge loads from the irrigation system were assumed 100 percent inorganic; loads in the irrigation system drains were assumed 25 percent inorganic due to algal synthesis. Table 30 summarizes the inorganic fractions of nutrient loads to Lake Helena for each modeling year.

Table 30. Inorganic Nutrient Fractions to Lake Helena

Year	Fraction Inorganic Nitrogen	Fraction Inorganic Phosphorus
1993	0.58	0.37
1994	0.83	0.70
1995	0.77	0.61
1996	0.68	0.51
1997	0.65	0.45
1998	0.56	0.36
1999	0.63	0.43
2000	0.69	0.52
2001	0.55	0.39
2002	0.48	0.38
2003	0.63	0.53

3.4 Light Penetration in Lake Helena

The BATHTUB model requires average Secchi depth to determine the nonalgal turbidity in the lake. Eight separate Secchi depth readings were collected in Lake Helena by Montana Fish Wildlife and Parks personnel during the summer of 2003. The readings ranged from 0.15 meters to 1.07 meters. Because data are only available for 2003, the average value of 0.41 meters was applied to all modeling years.

3.5 BATHTUB Calibration

The BATHTUB model for Lake Helena is currently not calibrated because of the limited water quality data available (one sampling event in 2002 and two events in 2003). The proposed water quality sampling plan for Lake Helena (Appendix H) will provide the necessary data to better understand nutrient response. However, to ensure the BATHTUB results are reasonable, the model output for the existing scenario was compared to the conditions observed in Lake Helena in 2002 and 2003, which are represented by DEQ data collected on 8/9/2002 and EPA data collected on 6/26/2003 and 8/29/2003.

The BATHTUB model offers the user several choices for nutrient sedimentation models, which determine the predicted in-lake concentrations from loading rates and residence time. Since insufficient historic lake water quality data are available to calibrate the model, the nutrient and chlorophyll *a* calibration factors were left at the default values of 1.0.

Table 31 and Table 32 show the average annual predicted total nitrogen and total phosphorus concentrations in Lake Helena under the existing scenario with a comparison to water quality observations collected in 2002 and 2003. The simulated total nitrogen average for 2002 is very close to the average observed concentration; the simulated average for 2003 is higher than the observed 2003 average. The simulated total phosphorus concentration for 2002 is very close to the average observed concentration; the simulated average for 2003 is less than the observed 2003 average.

Table 33 shows the yearly, predicted chlorophyll *a* concentrations in Lake Helena under the existing scenario with a comparison to water quality observations collected in 2002 and 2003. The BATHTUB model predicts an average chlorophyll *a* concentration of 53 μg/L, which is almost the same as the average of all samples collected in both 2002 and 2003 (52 μg/L). However, there is a greater variation in the observed data compared to the simulated concentrations. Thus, the model may be accurately depicting general eutrophication of the lake, rather than day-to-day variation detected by limited sampling data.

Table 31. Comparison of Observed and Simulated Total Nitrogen Concentrations (mg-N/L) in Lake Helena

Year	Simulated Total Nitrogen Concentration	Average Observed Total Nitrogen Concentration	Minimum Observed Total Nitrogen Concentration	Maximum Observed Total Nitrogen Concentration
1993	0.94	NA	NA	NA
1994	1.42	NA	NA	NA
1995	2.14	NA	NA	NA
1996	1.89	NA	NA	NA
1997	2.09	NA	NA	NA
1998	1.69	NA	NA	NA
1999	1.79	NA	NA	NA
2000	2.03	NA	NA	NA
2001	1.62	NA	NA	NA
2002	1.53	1.48	1.37	1.56
2003	1.49	0.82	0.65	0.99

NA: No nutrient water quality data were collected in Lake Helena from 1993 through 2001.

Table 32. Comparison of Observed and Simulated Total Phosphorus Concentrations (mg-P/L) in Lake Helena

Year	Simulated Total Phosphorus Concentration	Average Observed Total Phosphorus Concentration	Minimum Observed Total Phosphorus Concentration	Maximum Observed Total Phosphorus Concentration
1993	0.102	NA	NA	NA
1994	0.128	NA	NA	NA
1995	0.172	NA	NA	NA
1996	0.157	NA	NA	NA
1997	0.171	NA	NA	NA
1998	0.146	NA	NA	NA
1999	0.151	NA	NA	NA
2000	0.166	NA	NA	NA
2001	0.153	NA	NA	NA
2002	0.158	0.155	0.14	0.174
2003	0.157	0.226	0.19	0.377

NA: No nutrient water quality data were collected in Lake Helena from 1993 through 2001.

Table 33. Comparison of Observed and Simulated Chlorophyll *a* Concentrations (µg-N/L) in Lake Helena

Year	Simulated Chlorophyll *a* Concentration	Average Observed Chlorophyll a Concentration	Minimum Observed Chlorophyll *a* Concentration	Maximum Observed Chlorophyll *a* Concentration
1993	27	NA	NA	NA
1994	48	NA	NA	NA
1995	73	NA	NA	NA
1996	64	NA	NA	NA
1997	71	NA	NA	NA
1998	56	NA	NA	NA
1999	60	NA	NA	NA
2000	69	NA	NA	NA
2001	56	NA	NA	NA
2002	61	89	57	114
2003	45	14	5	26
Average for 2002 and 2003	53	52	31	70

NA: No nutrient water quality data were collected in Lake Helena from 1993 through 2001.

4.0 APPLICATION OF THE GWLF/BATHTUB MODELS

This section of the document discusses the various applications of the GWLF and BATHTUB models in support of TMDL development in the Lake Helena watershed.

4.1 Required Nutrient Reductions for Each TMDL Watershed

Nutrient TMDLs are required for four stream segments in the Lake Helena Watershed, representing Prickly Pear Creek, Sevenmile Creek, Tenmile Creek, and Spring Creek. The TMDLs are based on meeting the proposed interim water quality targets of 0.33 mg-N/L and 0.04 mg-P/L. As discussed in the main TMDL document, these targets are based on the best available data and provide the best means by which to ensure protection of beneficial uses until such time as they can be revised following an adaptive management approach.

The load reductions needed to achieve the TMDL target concentrations are determined by comparing current loads to allowable loads. For example, if the current load in a segment is 10 tons/year and the allowable load is 4 tons/year, a 60 percent reduction in loads is needed. Unfortunately, the current load is unknown in all segments due to a lack of water quality and/or flow data. The allowable load is also unknown in those segments without flow data. Simulated nutrient loads are therefore used to estimate the required reductions with some refinement based on available water quality and flow data. The necessary reductions should be revised in the future following additional sampling as described in Appendix H. This section summarizes the methods used to calculate the required loading reduction for each of the segments.

4.1.1 Prickly Pear Creek

The most downstream USGS Gage on Prickly Pear Creek (Number 06061500) has continuous flow monitoring and was used to estimate allowable nutrient loads. Daily flows recorded at this gage were scaled up by the ratio of the drainage areas of the listed segment and the gage (464/192) and added to the average daily flows released by wastewater treatment facilities. Total daily flows were then used with the nutrient water quality targets to estimate allowable loads at the mouth of Prickly Pear Creek. The average allowable loads were 33.7 mt/yr total nitrogen and 4.1 mt/yr total phosphorus.

Average, yearly simulated loads from the GWLF model (using weather data from 1993 through 2003) were 167.4 mt/yr and 32.1 mt/yr for nitrogen and phosphorus, respectively. Based on a comparison of the simulated and allowable loads, reductions of 80 percent total nitrogen and 87 percent total phosphorus are required to reduce loads to the allowable levels.

Very limited data are available from one water quality station (M09PKPRC02) located in this segment of Prickly Pear Creek (Table 34). The average observed total nitrogen concentration at this site is 2.03 mg-N/L, which would require an 84 percent reduction to meet the water quality target of 0.33 mg-N/L. The average observed total phosphorus concentration is 0.56 mg-P/L, which would require a 93 percent reduction to meet the water quality target of 0.04 mg-P/L.

Table 34. Observed Nutrient Data in Prickly Pear Creek Segment MT41I006_020

Sampling Site ID	Location	Date	TP (mg/L)	TN (mg/L)
M09PKPRC02	Prickly Pear Creek above Tenmile Creek	7/17/2003	0.797	2.660
		8/12/2003	0.522	1.940
		7/27/2004	0.736	2.600
		8/27/2004	0.458	1.900
		9/9/2004	0.492	1.690
		9/24/2004	0.345	1.370
		Average	0.558	2.027

For this listed segment, the reductions based on simulated loads are slightly lower than those estimated from observed water quality data. Because such limited observed water quality are available, the average annual simulated loads will be used to set the reductions of 80 percent total nitrogen and 87 percent total phosphorus.

To verify the accuracy of using an average annual allowable load to set the targets rather than the results from each modeling year, the gage data on Prickly Pear Creek were used to estimate allowable loads for each modeling year. These loads were then compared to the simulated yearly loads to calculate a reduction for each year (Table 35). The average reductions over the modeling period are 79 percent for total nitrogen and 87 percent for total phosphorus, which are almost identical to the reductions estimated from the average of the allowable and simulated loads. This comparison shows that loads simulated during extreme wet and dry years are not biasing the proposed reductions.

Table 35. Comparison of Annual and Average Annual Nutrient Load Reductions

Modeling Year	Allowable Load		Simulated Load		Required Reduction (%)	
	TN (mt)	TP (mt)	TN (mt)	TP (mt)	TN	TP
1993	44.0	5.33	291.0	52.29	85%	90%
1994	34.1	4.13	110.9	20.66	69%	80%
1995	44.0	5.33	106.4	21.08	59%	75%
1996	34.1	4.14	136.8	26.10	75%	84%
1997	40.4	4.90	145.2	29.23	72%	83%
1998	31.9	3.86	200.9	39.12	84%	90%
1999	25.6	3.11	163.0	31.89	84%	90%
2000	11.6	1.41	130.9	25.22	91%	94%
2001	16.3	1.98	189.3	36.94	91%	95%
2002	Incomplete flow data		226.3	42.56	Target loads could not be calculated due to incomplete flow data	
2003	No flow data available		149.4	28.14		
Average[1]	33.7	4.1	168.2	32.11	80	87
Average of reductions calculated for each year					79	87

[1] The average allowable loads are for all years with complete flow data (1980 through 2001), not just the modeling years presented in the table.

4.1.2 Tenmile Creek

Tenmile Creek is listed for nutrient impairment from the Helena water treatment plant to the mouth at Prickly Pear Creek. There is a USGS flow gage located in the most downstream segment (06063000), but only summer flows have been measured during a few sampling years. The average observed flow (36.6 cfs) was scaled up by drainage area (188/96.5) to estimate the average flow rate at the outlet of the subwatershed. Water quality targets were then applied to estimate an allowable nutrient load from this segment of Tenmile Creek.

The average estimated allowable total nitrogen and total phosphorus loads are 21.0 and 2.6 mt/yr, respectively. Average simulated total nitrogen load is 51.7 mt/yr, which would require a 59 percent reduction. Average simulated total phosphorus load is 6.47 mt/yr, which would require a 61 percent reduction.

Several water quality stations are located in this subwatershed with observed nutrient concentration data (Table 36). Water quality decreases below the confluence with Sevenmile Creek though it is impaired along the entire segment length. Average conditions throughout the segment result in estimated reductions of 46 for nitrogen and 49 percent for phosphorus.

In this segment, percent reductions based on simulated loads are slightly greater than reductions based on the water quality observations. To remain consistent with the other segments, reductions will be based on simulated loads and are 59 percent for total nitrogen and 61 percent for total phosphorus. It is acknowledged that this is possibly an over-estimate and contributes toward the TMDL's margin of safety (i.e., 13 and 12 percent for TN and TP, respectively).

Table 36. Observed Nutrient Data in Tenmile Creek Segment MT41I006_143

Sampling Site ID	Location	Date	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)
06063000	Tenmile Creek near Helena	6/5/1997	0.030	
		8/28/1997	0.020	
		10/9/1997	0.020	
		4/17/2002	0.029	0.434
		5/28/2002	0.043	0.362
		7/29/2002	0.019	0.352
		10/9/2002	0.009	0.286
		3/13/2003	0.210	1.058
		5/27/2003	0.059	0.350
		7/23/2003	0.022	0.668
		12/4/2003	0.008	0.331
06064100	Tenmile Creek at Green Meadow Drive	6/5/1997	0.050	
		8/28/1997	0.030	
		10/9/1997	0.010	
		4/17/2002	0.031	0.438
		5/28/2002	0.060	0.442
		7/29/2002	0.037	0.263
		10/9/2002	0.021	0.202
		3/13/2003	1.490	4.896
		5/27/2003	0.105	0.480
		7/24/2003	0.047	0.332
		12/4/2003	0.019	0.303
06064150	Tenmile Creek above Prickly Pear Creek	6/5/1997	0.060	
		8/28/1997	0.040	
		10/9/1997	0.030	
463438112091801	Tenmile Creek below Colorado Gulch	6/4/1997	0.030	
		8/28/1997	0.030	
		10/9/1997	0.030	
		4/17/2002	0.032	0.434
		5/28/2002	0.040	0.310
		7/29/2002	0.027	0.193
		10/9/2002	0.013	0.332
		3/13/2003	0.220	1.069
		5/27/2003	0.052	0.452
		7/23/2003	0.019	0.399
		12/4/2003	0.016	0.440
M09TENMC01	Tenmile Creek downstream of Green Meadow Golf Course	7/30/2001	0.029	0.410
M09TENMC02	Tenmile Creek upstream of Green Meadow Drive	7/31/2001	0.048	0.610
M09TENMC03	Tenmile Creek 3/4 mile upstream of Rimini	7/31/2001	0.005	0.710
		Average	0.079	0.613

4.1.3 Sevenmile Creek

Sevenmile Creek is listed for nutrients from its headwaters to the mouth at Tenmile Creek. There is no USGS flow gage on this stream with which to estimate allowable nutrient loads. Simulated flows in year 2003 are used to estimate the allowable load because the simulated concentrations that year are within the range of observed values. Thus, the relationship between flow and load is believed accurate. The simulated average total nitrogen concentration is 1.98 mg-N/L while observed values range from 0.33 to 5.16 with an average of 1.58 mg-N/L. Average simulated total phosphorus in 2003 is 0.28 mg-P/L. Observed values range from 0.03 to 1.61 with an average of 0.44 mg-P/L.

The allowable loads estimated from simulated flows in 2003 and the water quality targets are 1.99 mt/y of nitrogen and 0.24 mt/yr of phosphorus. The average simulated nitrogen load over the modeling period is 14.0 mt/y, which would require a reduction of 86 percent. The average simulated phosphorus load over the modeling period is 2.1 mt/y, which would require a reduction of 89 percent.

Water quality sampling with nutrient observations occurred at three locations (M09SVNMC01, M09SVNMC02, and USGS 463747112033801) from 1997 to 2003 with a total of 13 sampling events for phosphorus and 10 for nitrogen (Table 37). The average observed total nitrogen concentration is 0.93 mg-N/L, which would require a 65 percent reduction to meet the water quality target. The average total phosphorus concentration is 0.19 mg-P/L, which requires a 79 percent reduction to meet the water quality target.

In this segment, the simulated loads require a slightly higher reduction than observed water quality data. However, the allowable loads are based on simulated flow volumes and there is no available flow data from this creek to verify the flow results. The load reductions required in the receiving stream (Tenmile Creek) were approximately 60 percent for both total nitrogen and total phosphorus. These reductions are similar to those indicated by the water quality observations in Sevenmile Creek. Therefore, for Sevenmile Creek, the water quality observations will be used to set the reductions: 65 percent for total nitrogen and 79 for total phosphorus.

Table 37. Observed Nutrient Data in Sevenmile Creek Segment MT41I006_160

Sampling Site ID	Location	Date	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)
463747112033801	Sevenmile Creek at Mouth	6/5/97	0.150	
		8/28/97	0.080	
		10/9/97	0.070	
		4/17/02	0.038	0.462
		5/28/02	0.065	0.373
		7/29/02	0.049	0.243
		10/9/02	0.046	0.264
		3/13/03	1.610	5.163
		5/27/03	0.053	0.336
		7/24/03	0.068	0.382
		12/4/03	0.030	0.442
M09SVNMC01	Sevenmile Creek upstream of Green Meadow Drive	7/30/01	0.163	1.210
M09SVNMC02	Sevenmile Creek upstream of bridge, 150 feet north of railroad tracks	7/31/01	0.054	0.410
		Average	0.190	0.929

4.1.4 Spring Creek

Spring Creek is listed for nutrients from Corbin Creek to the mouth at Prickly Pear Creek. There is no USGS flow gage on this stream with which to estimate allowable nutrient loads. Simulated flows in year 2003 are used to estimate the allowable load because the simulated concentrations that year are within the range of values observed during 2003. The simulated average total nitrogen concentration in 2003 is 1.03 mg-N/L while observed values range from 0.37 to 1.05 with an average of 0.71 mg-N/L. Average simulated total phosphorus in 2003 is 0.17 mg-P/L. Observed values range from 0.04 to 0.21 with an average of 0.13 mg-P/L.

Table 38. Observed Nutrient Data in Spring Creek Segment MT41I006_080

Sampling Site ID	Location	Date	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)
M09SPRGC01	Spring Creek near Jefferson City	7/14/2003	0.039	0.370
		8/11/2003	0.205	1.050
		7/27/2004	0.050	0.240
		8/27/2004	0.010	0.280
		9/9/2004	0.009	0.110
		9/24/2004	0.007	0.200
		Average	0.053	0.375

Reductions based on simulated loads are 75 percent for total nitrogen and 83 percent for total phosphorus. Reductions based on observed 2003 concentrations are 54 percent for total nitrogen and 69 percent for total phosphorus. Reductions based on the average of all concentrations are 12 percent for total nitrogen and 25 percent for total phosphorus. The TMDL is based on the reductions estimated by the simulated loads based on the limited water quality data. It is acknowledged that this is possibly an over-estimate and contributes toward the TMDL's margin of safety. Table 39 summarizes the proposed load reductions for each subwatershed.

Table 39. Cumulative Nutrient Load Reductions for Listed Segments in the Lake Helena Watershed as Determined Using Observed Concentrations and Simulated Loads (Proposed Load Reductions Shown in Bold)

	Reductions Based on Observed Concentrations			Reductions Based on Simulated Loads		
Reach Description	**# Samples**	**TN**	**TP**	**TN**	**TP**	**Notes**
Spring Creek	6	54	69	**75**	**83**	Reductions based on simulated loads due to limited water quality data.
Tenmile Creek	39[A]	46	49	**59**	**61**	Reductions based on simulated loads to remain consistent with the other segments.
Sevenmile Creek	13[B]	**65**	**79**	86	89	Reductions based on observed concentrations due to limited available flow data and to be consistent with Tenmile reductions.
Prickly Pear Creek	6	84	93	**80**	**87**	Reductions based on simulated loads due to limited water quality data.

[A] 39 samples for TP and 27 for TN.
[B] 13 samples for TP and 10 for TN.

4.2 Natural Scenario

To provide a starting point for evaluating the magnitude of potential nutrient impairments, the GWLF model was also used to estimate nutrient loading in the Lake Helena watershed under "natural" conditions. It should be noted that the results from this scenario have not been used to derive nutrient concentration targets or load reductions. This scenario has been developed and evaluated for informational purposes. The existing scenario includes current land use conditions, wastewater treatment plant operations, septic systems, and the Helena Valley Irrigation District. The natural scenario models the watershed in its pre-disturbed condition. Septic systems, point sources, and the irrigation system are removed from the loading and all urban, agricultural, and silvicultural land uses are converted proportionally back to evergreen forest, shrubland, or grassland. Table 40 summarizes the land use areas for the two modeling scenarios.

Table 40. Land Use Areas for the Lake Helena Existing and Natural Conditions Modeling

Land Use	Existing (ac)	Natural (ac)
Bare Rock	84	84
LDRa	9,067	-
Quarries	234	-
Water	2,875	2,875
Transitional	1,853	-
Deciduous Forest	1,241	1,454
Evergreen Forest	154,204	171,484
Mixed Forest	36	36
Shrubland	37,014	46,787
Grassland	129,060	169,037
Pasture/Hay	14,892	-
Small Grains	16,925	-
Woody Wetland	1,270	1,270
Herbaceous Wetlands	421	421
Recent Clear-cut	522	-
Clear-cut Regrowth	3,571	-
Dirt Roads	3,326	-
Fallow	2,546	-
Row Crop	2,093	-
Non-system Roads	153	-
LDRb	2,950	-
Commercial/Industrial/Transportation	6,203	-
Urban/Recreational Grasses	1,001	-
Secondary Paved Roads	1,904	-
Total Watershed Area	393,445	393,445

Under natural conditions, grassland areas are assumed to have lower animal densities compared to grassland under existing conditions, which is often used for organized grazing. Soil compaction is therefore expected to be lower under natural conditions. Curve numbers for natural grassland area correspond to good condition, while under existing conditions, the curve numbers correspond to fair conditions.

Table 41 through Table 43 summarize the predicted increases in sediment, nitrogen, and phosphorus loads that have occurred from the natural condition to the existing condition. Very significant increases are projected to have occurred for all three pollutants in almost every subwatershed.

Table 41. Change in Annual Sediment Load from Existing to Natural Conditions in Lake Helena Modeling Subwatersheds

Subwatershed	Current Average Annual Sediment Load (mt)	Natural Average Annual Sediment Load (mt)	Percent Increase
Clancy Creek	3,774	1,427	164.5%
Corbin Creek	432	155	179.2%
Golconda Creek	228	116	95.8%
Jackson Creek	701	328	114.0%
Jennies Fork	378	121	212.9%
Lake Helena Overland Flow	5,614	326	1620.4%
Lump Gulch	2,953	1,013	191.4%
Middle Fork Warm Springs	365	119	207.2%
Middle Tenmile Creek	2,238	926	141.6%
North Fork Warm Springs Creek	168	75	123.9%
Prickly Pear above Spring Creek	1,929	977	97.4%
Prickly Pear above Lake Helena	765	150	411.4%
Prickly Pear above Lump Gulch	1,495	565	164.5%
Prickly Pear above WWTP outfall	1,829	318	474.4%
Prickly Pear above Wylie Drive	6,239	1,328	369.9%
Sevenmile Creek	2,874	967	197.3%
Silver Creek	6,525	1,183	451.3%
Skelly Gulch	1,277	561	127.5%
Spring Creek	2,083	739	181.9%
Tenmile above Prickly Pear	3,861	1,161	232.6%
Upper Tenmile Creek	1,522	659	130.8%
Warm Springs Creek	818	396	106.4%
Total Watershed Load	48,067	13,611	253.2%

Table 42.Change in Annual Nitrogen Load from Existing to Natural Conditions in Lake Helena Modeling Subwatersheds

Subwatershed	Current Average Annual Nitrogen Load (mt)	Natural Average Annual Nitrogen Load (mt)	Percent Increase
Clancy Creek	9.6	3.5	179.0%
Corbin Creek	1.0	0.4	191.5%
Golconda Creek	0.6	0.3	97.7%
Jackson Creek	1.7	0.8	121.5%
Jennies Fork	1.0	0.3	265.9%
Lake Helena Overland Flow	35.9	0.9	4030.3%
Lump Gulch	9.0	2.6	242.1%
Middle Fork Warm Springs	0.8	0.3	170.7%
Middle Tenmile Creek	6.7	2.4	181.0%
North Fork Warm Springs Creek	0.4	0.2	109.2%
Prickly Pear above Spring Creek	5.5	2.5	118.9%
Prickly Pear above Lake Helena	39.9	0.3	12762.8%
Prickly Pear above Lump Gulch	6.8	1.4	378.4%
Prickly Pear above WWTP outfall	9.5	0.7	1250.5%
Prickly Pear above Wylie Drive	23.3	3.3	599.6%
Sevenmile Creek	10.5	2.3	355.7%
Silver Creek	59.9	2.9	1979.9%
Skelly Gulch	3.5	1.3	167.0%
Spring Creek	5.8	1.8	224.1%
Tenmile above Prickly Pear	26.9	2.8	860.0%
Upper Tenmile Creek	3.9	2.0	98.8%
Warm Springs Creek	2.9	1.0	191.4%
To Lake Helena from Irrigation System	54.5	0	N/A
Total Watershed Load	319.4	33.8	845.4%

Table 43. Change in Annual Phosphorus Load from Existing to Natural Conditions in Lake Helena Modeling Subwatersheds

Subwatershed	Current Average Annual Phosphorus Load (mt)	Natural Average Annual Phosphorus Load (mt)	Percent Increase
Clancy Creek	1.81	0.73	148.1%
Corbin Creek	0.20	0.08	164.6%
Golconda Creek	0.12	0.06	85.4%
Jackson Creek	0.33	0.16	105.6%
Jennies Fork	0.18	0.06	209.4%
Lake Helena Overland Flow	3.08	0.17	1728.3%
Lump Gulch	1.48	0.55	169.4%
Middle Fork Warm Springs	0.17	0.06	180.6%
Middle Tenmile Creek	1.18	0.50	136.5%
North Fork Warm Springs Creek	0.08	0.04	111.0%
Prickly Pear above Spring Creek	1.03	0.52	97.1%
Prickly Pear above Lake Helena	13.79	0.07	20320.0%
Prickly Pear above Lump Gulch	0.85	0.29	189.0%
Prickly Pear above WWTP outfall	1.20	0.15	697.1%
Prickly Pear above Wylie Drive	3.14	0.70	351.8%
Sevenmile Creek	1.50	0.48	208.3%
Silver Creek	4.12	0.60	586.4%
Skelly Gulch	0.63	0.28	124.3%
Spring Creek	1.00	0.38	165.6%
Tenmile above Prickly Pear	2.36	0.59	300.6%
Upper Tenmile Creek	0.79	0.40	99.3%
Warm Springs Creek	0.44	0.21	111.1%
To Lake Helena from Irrigation System	6.90	0	N/A
Total Watershed Load	46.4	7.1	555.9%

4.3 Reduced Scenario

To determine the potential load reductions that may be achievable in the Lake Helena Watershed, a “reduced” scenario was run in GWLF. The following load reductions were assumed for the reduced scenario:

- Dirt Roads: BMPs will remove 60 percent of sediment as well as sediment-associated nutrients.
- Urban areas: BMPs will remove 80 percent sediment, 50 percent TP, and 30 percent TN based on typical ranges available in the literature (e.g., CWP, 2000).
- Abandoned Mines: BMPs will remove 79 percent of sediment as well as sediment-associated nutrients based on an evaluation of reclaimed mines in the Lake Helena watershed.
- Streambank Erosion: Anthropogenic loads have been reduced to reference conditions.
- Non-system roads are assumed closed and reclaimed, loads are zero.
- All septic systems are simulated as performing normally (i.e., no failing septic systems). Normally functions systems are assumed to discharge no phosphorus but nitrogen loads are only reduced due to preliminary treatment in the tank and plant uptake.
- Agriculture: Under existing conditions, agriculture is simulated with no BMPs. Under the reduced scenario, small grains are assumed in a wheat-grass rotation rather than a wheat-fallow rotation. For row crops, residuals are left on the field; disk turning in the spring replaces turn plowing in the fall. All fallow fields are assumed planted with alfalfa. Buffer strips are assumed to remove an additional 60 percent of sediment and 50 percent of nitrogen and phosphorus based on typical ranges available in the literature (e.g., Dillaha et al., 1989).
- Timber harvest land uses (recent clear cut and clear cut regrowth) are simulated as full-growth forest.
- Major point sources are assumed to discharge at instream nutrient target concentrations. All malfunctioning lagoons are simulated as properly functioning.
- Nutrient loads from the Helena Valley Irrigation District are assumed reduced by 50 percent based on best professional judgment.

In general, most of the load reductions proposed above are conservative (i.e., on the high end of the range of potential values) and assume that BMPs will be applied to each individual source (e.g., all of the dirt roads) within each of the broader source categories (e.g., dirt roads). These load reductions are also assumed to equate to application of “all reasonable land, soil, and water conservation practices.” It is acknowledged that achieving the proposed level of reductions may not be possible, but in the absence of site-specific data for each individual source this approach provides the only means to estimate the maximum load reductions that may be technologically achievable/feasible.

The results of the reduced scenario are presented in Appendix A by TMDL subwatershed.

4.4 Simplistic Build-out Scenario

Since the 1950's, population growth in the Lake Helena Watershed has averaged approximately 18 percent per decade. According to EPA's "Onsite Wastewater Treatment Systems Manual" (2002b), each person contributes 4.8 to 13.7 pounds of nitrogen and 0.8 and 1.6 pounds of phosphorus per year. As a result, there is a direct link between population growth/development and increased nutrient loading. While the extent to which population growth might lead to increased nutrient loading is dependant upon how and where domestic wastewater is treated and how and where the resulting development occurs, some incremental increase in nutrient loading is inevitable with a population increase.

A simplistic "build-out" scenario has been developed and modeled to demonstrate the extent to which nutrient loading might increase in the future. This scenario assumes that population growth will occur such that the municipal wastewater discharge facilities in the Cities of Helena and East Helena attain their design flow capacity, and the level of treatment at each of these facilities remains as it is today. Helena and East Helena are currently at approximately 50 percent and 47 percent of their design flow capacity, respectively. This scenario further assumes that all of the parcels currently platted and shown on the 2004 cadastral data base (i.e., a database of all legally defined pieces of land) will be developed.

The modified MRLC land use classification layers were used to select private parcels that are currently not classified as residential, commercial/industrial/transportation, or an active mine or quarry. 4,534 parcels were selected as a result of this analysis.

For this scenario, it was assumed that only one lot per parcel would be developed. This resulted in adding an additional 4,534 septic systems to the entire watershed. Because approximately 80 percent of the parcels are larger than 2 acres, this scenario is likely an underestimate of the number of lots that may actually be developed and the loading that may occur under full buildout.

The assumptions for the low intensity residential category, LDRb, were chosen to add 1.1 acres of new development for each of the 4,534 parcels, resulting in 4,987 acres of new development in the Lake Helena Watershed. The majority of the current land use categories converted were grasslands (50 percent), evergreen forest (30 percent), and shrubland (15 percent). To reflect additional road areas associated with the projected development, the current ratios of LDRb to unpaved roads were analyzed. This ratio was used as a multiplier to increase the unpaved road areas in each subwatershed proportionally to the new area of LDRb development. For those areas where the ratio resulted in a 0 percent increase in road area, a 15 percent increase in current road area was estimated based on similar subwatersheds (headwater subwatersheds). For those areas where the ratio resulted in more than a 100 percent increase in road area, a 100 percent increase in current road area was calculated.

It is acknowledged that this scenario represents a simplistic view of the future. However, the purpose of this scenario is to demonstrate what might happen in the future when the two largest wastewater discharge facilities attain their design capacity and much of the developable land in the watershed is developed.

Table 44 through Table 46 compare the sediment, nitrogen, and phosphorus loading under the existing and build-out scenarios. The subwatersheds with the greatest projected increases in nutrient loadings are Corbin Creek, Prickly Pear Creek, Middle Fork. Warm Springs Creek, and Upper Tenmile Creek. At the watershed scale there is a small net increase in sediment loading and fairly significant increases in nitrogen and phosphorus loading.

Table 44. Change in Annual Sediment Load from Existing to Buildout Conditions in Lake Helena Modeling Subwatersheds

Subwatershed	Current Average Annual Sediment Load (mt)	Buildout Average Annual Sediment Load (mt)	Percent Increase
Clancy Creek	3,774	3,776	0.1%
Corbin Creek	432	418	-3.3%
Golconda Creek	228	237	3.9%
Jackson Creek	701	706	0.7%
Jennies Fork	378	421	11.2%
Lake Helena Overland Flow	5,614	5,720	1.9%
Lump Gulch	2,953	2,995	1.4%
Middle Fork Warm Springs	365	366	0.1%
Middle Tenmile Creek	2,238	2,325	3.9%
North Fork Warm Springs Creek	168	174	3.8%
Prickly Pear above Spring Creek	1,929	1,971	2.2%
Prickly Pear above Lake Helena	765	767	0.3%
Prickly Pear above Lump Gulch	1,495	1,657	10.8%
Prickly Pear above WWTP outfall	1,829	1,894	3.5%
Prickly Pear above Wylie Drive	6,239	6,445	3.3%
Sevenmile Creek	2,874	3,119	8.6%
Silver Creek	6,525	7,030	7.7%
Skelly Gulch	1,277	1,415	10.8%
Spring Creek	2,083	2,098	0.7%
Tenmile above Prickly Pear	3,861	4,113	6.5%
Upper Tenmile Creek	1,522	1,590	4.5%
Warm Springs Creek	818	936	14.4%
To Lake Helena from Irrigation System			
Total Watershed Load	48,067	50,171	4.4%

Note: The negative percent increase in Corbin Creek is due to conversion of land uses with low vegetative cover to urban land uses, which are assumed to have established lawns.

Table 45. Change in Annual Nitrogen Load from Existing to Buildout Conditions in Lake Helena Modeling Subwatersheds

Subwatershed	Current Average Annual Nitrogen Load (mt)	Buildout Average Annual Nitrogen Load (mt)	Percent Increase
Clancy Creek	9.6	14.7	53.1%
Corbin Creek	1.0	3.2	207.7%
Golconda Creek	0.6	1.0	72.7%
Jackson Creek	1.7	1.8	9.8%
Jennies Fork	1.0	1.7	75.6%
Lake Helena Overland Flow	35.9	40.4	12.5%
Lump Gulch	9.0	14.6	61.3%
Middle Fork Warm Springs	0.8	1.7	117.1%
Middle Tenmile Creek	6.7	8.0	19.7%
North Fork Warm Springs Creek	0.4	0.6	53.5%
Prickly Pear above Spring Creek	5.5	9.5	72.3%
Prickly Pear above Lake Helena	39.9	90.1	125.8%
Prickly Pear above Lump Gulch	6.8	13.4	98.7%
Prickly Pear above WWTP outfall	9.5	12.9	36.2%
Prickly Pear above Wylie Drive	23.3	35.5	52.3%
Sevenmile Creek	10.5	14.6	39.0%
Silver Creek	59.9	71.4	19.3%
Skelly Gulch	3.5	6.3	77.8%
Spring Creek	5.8	11.4	97.2%
Tenmile above Prickly Pear	26.9	35.0	30.3%
Upper Tenmile Creek	3.9	7.9	104.0%
Warm Springs Creek	2.9	5.1	76.6%
To Lake Helena from Irrigation System	54.5	54.5	0.0%
Total Watershed Load	319	455	42.6%

Table 46. Change in Annual Phosphorus Load from Existing to Buildout Conditions in Lake Helena Modeling Subwatersheds

Subwatershed	Current Average Annual Phosphorus Load (mt)	Buildout Average Annual Phosphorus Load (mt)	Percent Increase
Clancy Creek	1.81	2.06	13.8%
Corbin Creek	0.20	0.29	44.0%
Golconda Creek	0.12	0.15	25.3%
Jackson Creek	0.33	0.34	3.1%
Jennies Fork	0.18	0.23	30.1%
Lake Helena Overland Flow	3.08	3.20	4.1%
Lump Gulch	1.48	1.75	18.4%
Middle Fork Warm Springs	0.17	0.23	31.9%
Middle Tenmile Creek	1.18	1.26	7.0%
North Fork Warm Springs Creek	0.08	0.09	15.6%
Prickly Pear above Spring Creek	1.03	1.28	24.3%
Prickly Pear above Lake Helena	13.79	45.40	229.2%
Prickly Pear above Lump Gulch	0.85	1.24	45.7%
Prickly Pear above WWTP outfall	1.20	1.33	10.4%
Prickly Pear above Wylie Drive	3.14	3.69	17.4%
Sevenmile Creek	1.50	1.75	16.7%
Silver Creek	4.12	4.74	15.1%
Skelly Gulch	0.63	0.81	28.9%
Spring Creek	1.00	1.28	28.0%
Tenmile above Prickly Pear	2.36	2.74	15.9%
Upper Tenmile Creek	0.79	1.07	34.5%
Warm Springs Creek	0.44	0.59	34.5%
To Lake Helena from Irrigation System	6.90	6.90	0.0%
Total Watershed Load	46	82	77.7%

4.5 Lake Helena Response to Scenarios

The BATHTUB model was used to simulate the potential impacts of the natural, reduced, and buildout scenarios on Lake Helena. The results are summarized in Table 47. Model results indicate that lake water quality is significantly worse today, under the existing condition, compared to the natural condition, and is projected to deteriorate further under the simplistic full build-out scenario. The results of the reduced scenario indicate slightly improved conditions compared to the existing condition.

Table 47. Comparison of Simulated Average Total Nitrogen, Total Phosphorus, and Chlorophyll *a* Concentrations in Lake Helena Under Four Modeling Scenarios

Parameter	Natural	Existing	Reduced	Buildout
Total Nitrogen (mg-N/L)	0.41	1.67	1.51	2.00
Total Phosphorus (mg-P/L)	0.115	0.149	0.136	0.263
Chlorophyll *a* (μg/L)	12.11	56.3	51.3	72.8

5.0 UNCERTAINTY OF THE GWLF/BATHTUB MODELING

There were several goals of the Lake Helena nutrient and sediment modeling effort:

- To determine the relative significance of each of the sediment and nutrient source categories within each TMDL subwatershed.
- To determine how sediment and nutrient loads in the watershed have been affected by anthropogenic activities (i.e., comparison of existing and natural scenarios) and the resulting impact to Lake Helena.
- To determine how loads might change in the future with increased development of the watershed and the resulting impact to Lake Helena.
- To determine allowable and existing loads at various points in the watershed that lack observed flow and/or water quality data.

Relatively simple models were chose to accomplish these goals because of the lack of data with which to calibrate more complex models. The models were set up using the best available data and output was compared to the limited observed data set. Output from the models was also reviewed by the project team to ensure that it was reasonable compared to local knowledge of the watershed. Errors in the model output are present and expected, and are primarily governed by errors and uncertainty with the following model inputs:

- Only one weather station was available to represent an area of greater than 600 square miles with extreme variations in elevation.
- Limited information was available on the timing or location of water withdrawals and other anthropogenic impacts to flows.
- No information was available on the extent of timber harvest on private land. We assumed that harvesting occurs at a continuous rate allowing for a 90-year harvest cycle (1/90 of private land is harvested each year). However, it is more likely that large cuts occur sporadically.
- Only limited data were available on the extent of failing septic systems in the watershed. We assumed that 7 percent of the systems were failing, but this is likely an under-estimate in certain parts of the watershed and an over-estimate in others.
- Applying constant monthly loads from the Helena Valley Irrigation District, point sources, and septic systems may oversimplify the loading from these sources.
- There is a general lack of understanding about the interaction between surface water and groundwater in the Helena Valley.

Despite these limitations, the GWLF and BATHTUB models are believed to be useful tools to help further the understanding of water quality in the Lake Helena watershed. They were used, **in combination with all other available information**, to identify those waterbodies that are impaired and to develop all necessary TMDLs. The limitations of the models were taken into consideration during their application as follows:

- The primary purpose of the GWLF modeling effort was to determine the relative difference in sediment and nutrient loads from each significant source category (e.g., point sources, roads, septic systems). These loads are most sensitive to annual flow volumes, which are largely driven by the runoff that occurs during the wettest months. GWLF performs reasonably well at matching annual flows as well as spring snowmelt volumes (refer to Section 2.6.1). Default values were used for most of the loading parameters (e.g., runoff concentrations, soil nutrient concentrations) due to a lack of local data and to ensure the modeling results are consistent with previously validated studies. The relative difference between the various source categories is therefore believed reasonable, even though the magnitude of the loads might be in error.

- Another purpose of the modeling effort was to evaluate the extent to which sediment and nutrient loads in the watershed have been affected or might be affected by anthropogenic activities. This was done by comparing the results of the existing scenario to artificial "natural" and "build out" scenarios. The results of the GWLF/BATHTUB model under natural conditions are considered reasonable because transport parameters for undisturbed land uses are well established. The results of the GWLF/BATHTUB model for the build-out scenario likely have a high degree of uncertainty due to the simplifying assumptions that were made. However, the results are believed to provide a reasonable estimate of the potential increase in loads.
- The GWLF model was also used to estimate the nutrient load reductions required to meet the proposed interim water quality targets. Accurate estimates of these reductions require the model to correctly simulate both existing flows (to calculate the allowable loads in streams without flow data) and existing loads. It is acknowledged that there is a fair amount of uncertainty in these values due to the limitations identified above. The reductions simulated by the model were therefore tempered by a comparison to the available data; however, the available data are also limited (i.e., few samples, little seasonal variability). The proposed reductions should therefore be viewed as preliminary goals to be refined during an adaptive management process.
- Finally, the modeled loads presented in Appendix A have purposefully been rounded to a minimum of significant figures so that the loads do not appear to be more accurate than they are.

6.0 REFERENCES

Canfield, D.E. and R.W. Bachmann. 1981. Prediction of total phosphorus concentrations, chlorophyll-*a* and Secchi disc in natural and artificial lakes. *Can. J. Fish. Aq. Sci.*, 38, 414-423.

Center for Watershed Protection. 2000. National Pollutant Removal Performance Database for Stormwater Treatment Practices, 2nd Edition. Prepared by Winer, Rebecca. Prepared for U.S. EPA Office of Science and Technology.

Clark, Don. 2004. Personal communication to Julie Tsatsaros via email dated November 8, 2004 concerning the City of Helena WWTP.

Damschen & Associates. 1998. Helena Area Wastewater Treatment (HAWT) Facility Plan. Damschen & Associates, Inc.

Dillaha, T.A., R.B. Renear, S. Mostaghimi, and D. Lee. 1989a. Vegetative filter strips for agricultural nonpoint source pollution control. *Transactions of the American Society of Agricultural Engineers* 32(2):513-519.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. GWLF, Generalized Watershed Loading Functions, Version 2.0, User's Manual. Dept. of Agricultural & Biological Engineering, Cornell University, Ithaca, NY.

Ingman, G. 2004. Personal communication during conference call dated November 4, 2004 concerning the City of Helena WWTP.

LCCHD. 2002. Inventory of On-Site Wastewater Treatment Systems. Lewis and Clark County Health Department, Helena, MT, April 2002.

Moore, K. 2005. Personal communication with Julie Tsatsaros, May 2005. Lewis and Clark County.

Musket, J. 2005. Personal communication with Julie Tsatsaros, August 2005. City of East Helena.

NRCS. 2003. Upper Yellowstone River Watershed Land Cover Assessment, Final Report. Natural Resources Conservation Service, Montana, August 2003.

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

Rosgen, D.L. 2001. A Practical Method of Computing Streambank Erosion Rate. Proceedings of the Seventh Federal Interagency Sedimentation Conference, Vol. 2, pp. II - 9-15, March 25-29, 2001, Reno, NV

Schwab, G.O., D.D. Fangmeier, W.J. Elliot, and R.K. Frevert. 1993. Soil and Water Conservation Engineering, Fourth Edition, John Wiley & Sons, Inc, NY.

SCS. 1986. Urban Hydrology for Small Watersheds. Technical Release 55, U.S. Department of Agriculture, Soil Conservation Service, Engineering Division, Washington, DC.

Sun, G. and S. G. McNulty. 1998. Modeling soil erosion and transport on forest landscape. In: Winning solutions for risky problems: Proceedings of conference 29; 1998 February 16-20; Reno, NV. Steamboat Springs, CO: International Erosion Control Association: 189-198.

Stuart, Bo. 2004. Personal communication to Taylor Greenup via email dated November 8, 2004 concerning the Helena National Forest.

Tetra Tech. 2000. Watershed Characterization System User's Guide, Version 1.1. Developed for the Environmental Protection Agency, Region 4.

Toy, T.J., G.R. Foster, and J.R. Galetovic. 1998. Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands. Office of Technology Transfer, Western Regional Coordinating Center, Office of Surface Mining. Available at http://www.ott.wrcc.osmre.gov/library/hbmanual/rusle/frontmatter.pdf

USEPA. 1997. Technical Guidance Manual for Developing Total Maximum Daily Loads, Book 2: Streams and River. EPA 823-B-97-002.

USEPA. 2002a. Wastewater Technology Fact Sheet, Slow Rate Land Treatment. EPA 832-F-02-012, September 2002.

USEPA. 2002b. *Onsite Wastewater Treatment Systems Manual.* EPA/625/R-00/008. February 2002.

USEPA. 2004. Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area.

U.S. Forest Service. 1998. Soil Survey of Flathead National Forest Area, Montana, in cooperation with Montana Agricultural Experiment Station, Natural Resources Conservation Service, and U.S. Forest Service.

Walker, W.W., Jr. 1987. Empirical Methods for Predicting Eutrophication in Impoundments. Report 4–Phase III: Applications Manual. Technical Report E-81-9. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Wischmeier, W.H., and Smith, D.D., 1978. Predicting Rainfall Erosion Losses — A Guide to Conservation, Agricultural Handbook 537. Planning, Science and Education Administration. US Department of Agriculture, Washington, DC, 58 pp.

Appendix D

Supplemental Sediment Assessment

Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report

August 31, 2006

Prepared for the Montana Department of Environmental Quality

Prepared by the U.S. Environmental Protection Agency,
Montana Operations Office
With Technical Support from Tetra Tech, Inc.
and PBS&J, Inc.

Project Manager: Ron Steg

Contents

1.0 Introduction 1
2.0 Sediment Sources – Remote Quantification 3
 2.1 Sediment from Streambank Instability 5
 2.2 Reference Streambank Erosion 6
3.0 Abandoned Mine Related Sediment 9
4.0 Potential Sediment Loading Risk from Culvert Failure 11
 4.1 Additional Roads Assessment Using WEPP:Road 11
5.0 Sediment Modeling Results 13
 5.1 Remote sediment source quantification 13
 5.2 Sediment from Streambank Instability 40
 5.3 Abandoned Mine Related Sediment 44
 5.4 Potential Sediment Loading Risk from Culvert Failure 47
 5.5 WEPP:Road, Additional Roads Assessment 49
6.0 Conclusions 50
7.0 References 51

Tables

Table 1-1. Water Quality Status of Suspected Sediment Impaired Water Bodies and Required TMDLs in the Lake Helena Watershed. D-2
Table 2-1. Bank Retreat Rates Used for Banks of Varying Severity of Erosion D-5
Table 5-1. Summary of Channel Changes on Upper Prickly Pear Creek since 1956 D-14
Table 5-2. Aerial Sediment Source Assessment: 303(d) Channel Form D-16
Table 5-3. Aerial Sediment Source Assessment: 303(d) Channel Alterations D-20
Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations D-23
Table 5-5. Historical Aerial Sediment Source Assessment of Upper Prickly Pear Creek: Channel Form D-36
Table 5-6. Historical Aerial Sediment Source Assessment of Upper Prickly Pear Creek: Channel Features and Alterations D-37
Table 5-7. Historical Aerial Sediment Source Assessment of Upper Prickly Pear Creek: Channel Observations D-38
Table 5-8. Sediment Loads from Eroding Streambanks by Source D-40
Table 5-9. Collected Lake Helena BEHI data D-42
Table 5-10. Sediment Loads by Abandoned Mine Site D-45
Table 5-11. Sediment Loads from Abandoned Mine Sites by Sub-Watershed D-46
Table 5-12. Estimates of Sediment Loads from Culvert Failure D-48

Figures

Figure 2-1. Source Assessment Reach Breaks of the Lake Helena 303(d) Sediment Impaired Streams D-4
Figure 5-1. Locations of the 2003 and 2005 Field Survey Source Assessment Sites D-15

1.0 INTRODUCTION

Twenty stream segments in the Lake Helena Watershed have been placed on Montana's 303(d) list for suspected water quality impairments due to sediment. Data analyzed for the Volume I report indicated that sediment TMDL development was necessary for 17 of the 20 listed segments (Table 1-1). The Generalized Watershed Loading Function (GWLF) model was chosen to simulate sediment and nutrient loads from large-scale land uses in the Lake Helena watershed. Additional and/or complimentary sediment assessment methodologies were implemented to account for site-specific and in-stream sediment sources that GWLF was unable to account for during the modeling process. These included:

- *Remote sensing using GIS and air photos.* These assessments were complimentary to the GWLF analysis, which was conducted at a sub-watershed scale. The results from the remote sensing analysis allowed for the identification and delineation of specific source areas to facilitate future restoration efforts, and were also used as a means to validate the GWLF generated results.
- *Stream bank erosion assessments.* GWLF did not account for sediment loading from stream bank erosion. Therefore, the results of this assessment were added to the sediment loads generated by GWLF to develop the total sediment loading for each assessment unit.
- *Analysis of sediment loading from abandoned mines.* GWLF did not account for sediment loading from abandoned mines. Therefore, the results of this assessment were added to the sediment loads generated by GWLF to develop the total sediment loading for each assessment unit where abandoned mines constituted a potential sediment source.
- *Culvert failure analysis.* The results from this analysis have not been incorporated into the total sediment loads estimated for each assessment unit. Potential culvert failures represent a potential future source of sediment. These results have been incorporated into the allocation component of the TMDL process presented in Appendix A of Volume II.
- *WEPP:Road modeling analysis.* The decision to implement this modeling exercise was related to scale issues associated with the GWLF model. GWLF functions at a watershed or sub watershed scale, but the input parameters lack the detail to model site-specific road related sediment loading. In order to assist in the identification of road sediment source areas, site specific road data was collected and modeled using WEPP:Road. The results will be used to guide future restoration activities and have been compared to the results generated by GWLF for validation purposes and as one means to assess potential uncertainty.

This report summarizes the additional sediment assessment methodologies, assumptions and results for the sediment-listed watersheds.

Table 1-1. Water Quality Status of Suspected Sediment Impaired Water Bodies and Required TMDLs in the Lake Helena Watershed.

Water Body Name and Number	Suspected Impairment Causes	Conclusions	Proposed Action
Clancy Creek, MT41I006_120	Sediment	Impaired	A TMDL will be written.
Corbin Creek, MT41I006_090	Sediment	Impaired	A TMDL will be written.
Golconda Creek, MT41I006_070	Sediment	Not impaired	A TMDL will not be written.
Jackson Creek, MT41I006_190	Sediment	Not impaired	A TMDL will not be written.
Jennie's Fork, MT41I006_210	Sediment	Impaired	A TMDL will be written.
Lump Gulch, MT41I006_130	Sediment	Impaired	A TMDL will be written.
Middle Fork Warm Springs Creek, MT41I006_100	Sediment	Impaired	A TMDL will be written.
North Fork Warm Springs Creek, MT41I006_180	Sediment	Impaired	A TMDL will be written.
Prickly Pear Creek, MT41I006_060	Sediment	Impaired	A TMDL will be written.
Prickly Pear Creek, MT41I006_050	Sediment	Impaired	A TMDL will be written.
Prickly Pear Creek, MT41I006_040	Sediment	Impaired	A TMDL will be written.
Prickly Pear Creek, MT41I006_030	Sediment	Impaired	A TMDL will be written.
Prickly Pear Creek, MT41I006_020	Sediment	Impaired	A TMDL will be written.
Sevenmile Creek, MT41I006_160	Sediment	Impaired	A TMDL will be written.
Skelly Gulch, MT41I006_220	Sediment	Impaired	A TMDL will be written.
Spring Creek, MT41I006_080	Sediment	Impaired	A TMDL will be written.
Tenmile Creek, MT41I006_141	Sediment	Not impaired	A TMDL will not be written.
Tenmile Creek, MT41I006_142	Sediment	Impaired	A TMDL will be written.
Tenmile Creek, MT41I006_143	Sediment	Impaired	A TMDL will be written.
Warm Springs Creek, MT41I006_110	Sediment	Impaired	A TMDL will be written.

2.0 SEDIMENT SOURCES – REMOTE QUANTIFICATION

Remote sediment source quantification for the 303(d) sediment impaired streams was conducted with a GIS using digital orthophotos and topographic maps. Source assessment of streams within the Helena area was conducted on 1-foot resolution, true color orthophotos taken in 2004. Many of the headwater streams were assessed on 1-meter resolution, black and white orthophotos taken between 1995 and 1998. GIS layers for roads, railways, mines, and the GPS positions of the 2003 and 2005 field source assessments were also incorporated to aid the analysis.

The 303(d) sediment impaired streams were broken into reaches on the basis of land ownership, topography, and land use. The 17 sediment impaired stream segments were broken into a total of 93 reaches (Figure 2-1). For each stream reach, observations were recorded for the following variables: reach length, length of reach with road encroachment (left and right banks), valley length, length of reach with rip-rap (left and right banks), valley slope, jetties, channel sinuosity, dikes, channel slope, percent of reach affected by mining, bankfull width, and land use.

Qualitative information was also recorded for observations such as degree of channelization, number of road crossings, and overall channel condition. Measurements were made in a GIS using the measure tool. Stream length was measured along the center of the channel, while stream sinuosity was derived from the center channel length divided by the valley length. Channel slope was derived from the valley slope divided by the stream sinuosity. Elevation ranges for slope measures were taken from the USGS 1:24,000 digital topographic maps. Road encroachment measured the length of stream reach where a road or railway was located adjacent to the stream (within 100 feet), and was either altering the natural stream course and/or restricting access to the floodplain. A GIS calculation was performed that tabulated the length of roads and railways within 100 feet of each reach. Percent of each reach affected by mining, so as to disrupt the channel course, was either directly measured or estimated based on field knowledge of the streams and the location of mines. Other characteristics, such as rip-rap, jetties, dikes, and land use were inferred from the photos, and are representative of features that were visible at the scale of the photo. GPS positions from the 2003 and 2005 field source assessments were used to help tabulate rip-rap, jetties, and dikes.

An historical analysis of channel alterations was conducted for a portion of Prickly Pear Creek, from just above the confluence with Beavertown Creek to Montana City. This area corresponded with portions of segments MT41I006_060 and MT41I006_040, and all of segment MT41I006_050. Stereo-pair, black and white aerial photos taken in 1956 at a scale of 1:12,000 were obtained from the Montana Department of Transportation. The photographs represented channel condition before the construction of Interstate 15. The historical photographs were analyzed and compared to metrics from recent photographs. Photo measurements were made using a digitizing planimeter. In order to compare channel metrics to those measured from the orthophotos, the historical measurements were normalized using the ratio between the valley lengths of the 1956 photos and the recent orthophotos.

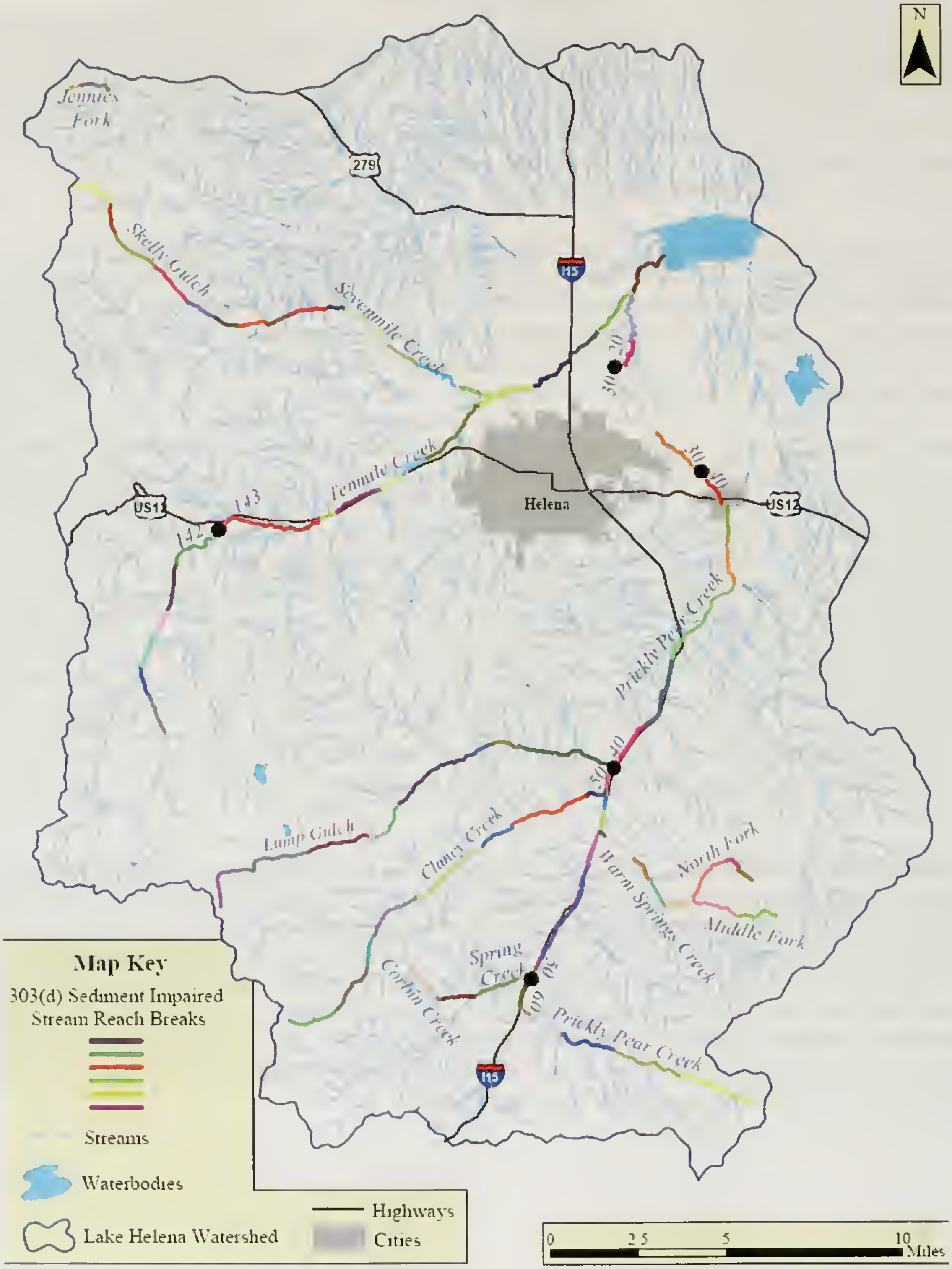


Figure 2-1. Source Assessment Reach Breaks of the Lake Helena 303(d) Sediment Impaired Streams

2.1 Sediment from Streambank Instability

Streambank erosion is an inherent part of channel evolution and can contribute significant quantities of sediment to stream system sediment loads based on a combination of climatic and physiographic features. However, anthropogenic impacts, such as grazing, mining, timber harvest, road encroachment, riparian vegetation removal, and/or channel alterations can result in elevated rates of streambank erosion. The intent of this analysis was to provide an estimate of sediment loads from streambank erosion within the listed watersheds. Modeled sediment load was allocated into two source categories: anthropogenic or natural.

Due to the size of the Lake Helena TPA and the large number of listed stream miles, a coarse filter approach was used to estimate the sediment load related to stream bank instability. Bank Erosion Hazard Index (BEHI) assessments were conducted on eroding streambanks within representative intra-segment reaches. Eroding streambanks were surveyed by Land & Water/PBS&J personnel during the preliminary source assessment in August, 2003, and March, 2005 during the sediment source assessment. Results from sampled reaches were averaged and extrapolated to the full perennial stream length within a listed stream segment's watershed. The BEHI assessments were based on a slightly modified version of the Rosgen (1996) method to characterize stream bank conditions into numerical indices of bank erosion potential.

The modified BEHI methodology evaluated a stream bank's inherent susceptibility to erosion as a function of six factors, including:

1. The ratio of stream bank height to bankfull stage.
2. The ratio of riparian vegetation rooting depth to stream bank height.
3. The degree of rooting density.
4. The composition of stream bank materials.
5. Stream bank angle (i.e., slope).
6. Bank surface protection afforded by debris and vegetation.

To determine annual sediment load from eroding stream banks in each BEHI category, bank retreat rates developed by Rosgen (2001) were utilized (Table 2-1). The rate of erosion was then multiplied by the area of eroding bank (square feet) to obtain a volume of sediment per year, and then multiplied by the sediment density (average bulk densities were 1.41 g/cm^3 within granitic parent material, and 1.31 g/cm^3 outside of the batholith, USDA, 1998) to obtain a mass of sediment per year.

Table 2-1. Bank Retreat Rates Used for Banks of Varying Severity of Erosion

Bank Erosion Hazard Condition	Retreat Rate from Rosgen 2001 (ft/yr) – used for A and B channels	Retreat Rate from Rosgen 2001 (ft/yr) – used for C channels
Low	0.045	0.09
Moderate	0.17	0.34
High	0.46	0.7
Severe	0.82	1.2

Total sediment load from eroding streambanks of each sediment-listed stream was generated by averaging intra-segment (reach) sediment loads (on a percentage stream length basis), and applying this value to the entire perennial stream length within the segment. For this purpose, each listed segment was divided into approximately 5 assessment reaches (actual number reaches varied from 2 to 10) based on homogeneity of land use, vegetation and geomorphic character. Each listed reach outside the Helena National Forest boundary was visited, and BEHI measurements were conducted where eroding streambanks were observed. Representative eroding streambanks were surveyed using the BEHI methodology. The survey results were extrapolated to an identified percentage of the reach (or segment) length. Total extrapolated eroding, and non-eroding, streambank lengths were calculated through direct observation during the source assessment, and/or through the aerial photo assessment.

For example, if the BEHI analysis resulted in an average segment sediment load of 0.02 tons/foot/year from a segment's surveyed eroding streambank; the total channel length is 3 miles, and the condition of the surveyed eroding streambank represented 20% of the total channel length. (This 20% example relates to total eroding streambanks from river right and river left.) The 0.02 tons/foot/year is extrapolated to the entire eroding perennial streambank length of the segment; i.e., 20% of 3 miles (15,840 ft.) of streambank is 3168 feet; applying the unit based sediment load of 0.02 tons (0.02 x 3168 ft) results in a total sediment load from eroding streambanks from this theorized segment of 63.4 tons/yr.

Additionally, the total sediment load related to eroding streambanks was divided between naturally occurring erosion, and that which appeared to be anthropogenically induced. This allocation was determined through observations made during field reconnaissance and by aerial photo assessments. Land uses adjacent to, or in some cases upstream from, eroding streambanks were surveyed. The majority of land uses found to contribute to eroding streambanks included channel encroachment or sinuosity reductions related to transportation infrastructure, which includes interstate highways, city/county roads, forest roads, and rail-roads; riparian vegetation reduction caused by grazing in or near the riparian zones; and historic mining activities. Based on these assessment results, percentages of eroding bank lengths were generated and allocated to natural or anthropogenic sources within each segment.

The watershed scale estimates of streambank erosion are based on extrapolation from field surveys conducted on representative listed stream segment reaches. The extrapolation methodology likely overestimates the total amount of streambank erosion. Additionally, due to constraints posed by physical infrastructure, and access conflicts, it may not be practical or possible to restore all areas of human-caused streambank erosion to reference levels. Therefore, this load reduction is likely an overestimate.

2.2 Reference Streambank Erosion

Reference level sediment loads were developed as target values for anthropogenically related streambank erosion sediment loads. Reference BEHI values, stratified by Rosgen (1996) stream type were developed from the Beaverhead-Deerlodge National Forest field measurement database, which is composed of survey data collected across the Beaverhead-Deerlodge National Forest.

The Beaverhead-Deerlodge has systematically conducted stream reach surveys of representative reaches throughout southwest Montana since 1991. This survey data has been synthesized in a single database. Numerous habitat, hydraulic and morphometric parameters (including BEHI) were collected at each survey site. Data collection is based on the Rosgen (1996) stream classification system. Though the majority of surveyed stream reaches were impacted by a variety of anthropogenic influences, a database of reference conditions, stratified by Rosgen stream type, was distilled from the overall database. These reference database values were used to establish the reference BEHI conditions for the Lake Helena

TMDL analysis area. Reference BEHI scores are as follows: A channels = 21.06, B channels = 20.49, C channels = 20.32, and E channels = 18.77 (Bengeyfield, 1999).

Modeled reference sediment loads used the same BEHI sediment load model that was used to model the existing condition scenario (section 1.2.1 above). Reference BEHI values were incorporated into the model with a reduced length of eroding streambank in order to calculate reference sediment yield. Reference BEHI values for segments composed of multiple stream types were generated by averaging the BEHI values of the relevant stream types. Based on the construction of the model, changing these two parameters resulted in the generation of the reference sediment load from eroding streambanks.

Reference values and the portion of the total load considered "natural" are not analogous and therefore the values of the two sediment load categories vary. Calculated reference sediment load values will be used as targets for sediment load reduction from anthropogenically related eroding streambanks. Reference is defined as conditions that would be found in the absence of any anthropogenic activity within the watershed. Natural is defined as existing streambank erosion with no directly attributable source land-use. Due to the nature of the channel alteration/modification assessment, an inherent margin of error is introduced into this survey. Additionally, using reference values as reduction targets may overestimate sediment load reduction due potential lack of access, or constraints posed by physical infrastructure.

3.0 ABANDONED MINE RELATED SEDIMENT

Sediment loads associated with abandoned mining were calculated for sites throughout the Lake Helena watershed. Potential sediment source locations were delineated from the High Priority Abandoned Hardrock Mine Sites, and Abandoned and Inactive Mines of Montana, as well as the National Hydrography Dataset GIS data layers. Potential sediment source delineation criteria were as follows: mine sites within 300 feet of stream, or mines within 1000 feet of stream in areas where slopes are greater than 30 percent.

This GIS exercise generated 223 mines deemed to be potential sediment sources. These mines were cross-referenced with Montana Bureau of Mines and Geology (MBMG) reports, and the Montana State Bureau of Abandoned Mines. Available MBMG documents reported that 12 of the Abandoned-Inactive mines were probable sediment sources. Additionally, records of High Priority Abandoned Hardrock Mine Sites from the Montana State Bureau of Abandoned Mines indicated that eighteen (18) additional mine sites were probable sediment sources. The MBMG and Bureau of Abandoned Mine reports contained CAD drawings of the mine sites with areas and volumes of tailings and waste rock piles.

Area based sediment loads for waste rock piles were obtained from a report produced by CDM, for USEPA, for use in the Upper Tenmile Creek Mining Area Superfund site. CDM used RUSLE version 1.06 to generate sediment yield of 27 tons/acre/year from nose slopes, and 16 tons/acre/year from side slopes of waste rock piles in loamy-sand textured soil. Sediment delivery ratios were generated based on methodology described in *Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands* (Toy and Galetovic, 1999). Five of the High Priority Abandoned Mine sites were reported to be reclaimed. The level of reclamation, and associated reduction in sediment production was field-assessed in the summer of 2005 at each of the five sites. Of the five mine sites, only one (Alta) was not fully vegetated and continued to generate sediment. Pre- and post-reclamation sediment loads were calculated for reclaimed mine scenarios.

4.0 POTENTIAL SEDIMENT LOADING RISK FROM CULVERT FAILURE

Culvert failure is typically a result of run-off or stream flow ponding behind the culvert inlet. Ponding may result from debris obstructing run-off/stream flow conveyance, or the installation of an undersized culvert. Historically, most culverts were sized to convey a twenty-five (25) year discharge event (B. Stuart, personal communication). This return interval has been determined to be inadequately short, and has resulted in numerous undersized culverts on the landscape. Culverts currently being installed are typically sized to convey at least a 100-year discharge event. The large numbers of undersized culverts on the landscape have resulted in an increased probability of sediment loading from culvert fill material during catastrophic culvert failure. Surveys indicate that many of the culverts within the Lake Helena TPA are undersized (B. Stuart, personal communication) and at increased risk of failure.

A culvert hazard analysis was conducted by the Helena National Forest in the Poorman Creek watershed in 1996. Poorman Creek is not within the Lake Helena TPA; however, the similarity in age of the forest road infrastructure justifies the extrapolation of analysis results to forest roads within the Lake Helena TPA (B. Stuart, personal communication). Culverts dimensions were surveyed and risk of failure was qualitatively rated as high, moderate, or low. On a percentage basis, the Poorman Creek culvert hazard analysis reported: high risk of culvert failure = 45%, moderate risk of culvert failure = 30%, low risk of culvert failure = 25%. The corresponding percentages were extrapolated and applied to the Lake Helena TPA.

4.1 Additional Roads Assessment Using WEPP:Road

An alternative road sediment analysis was conducted in addition to the GWLF modeling. This secondary modeling effort utilized the WEPP:Road module developed by the Rocky Mountain Research Station, USFS. The decision to implement this modeling exercise was related to scale issues associated with the GWLF model. GWLF is well-suited for estimating sediment loads at the watershed scale, but the input parameters lack the detail to model site specific road related sediment loading. In order to assist in the identification of road sediment source areas, site specific road data was collected and modeled using WEPP:Road.

A stratified random sample was conducted in each sediment listed watershed. All stream-road crossings within each listed watershed were identified, and assigned a unique numeric identifier through GIS. (Only roads available on the most recent GIS roads layer were used, it is likely that roads are present on the landscape that were not captured by the GIS roads layer.) Random numbers were assigned to each road crossing, and then ranked in ascending order. The sampling protocol required that 10% of all road crossings within each sediment listed watershed would be visited and surveyed. The requisite number of crossings were surveyed in each watershed by Land & Water/PBS&J personnel during the spring of 2005.

WEPP uses the RockClime climate generator to model weather events over a thirty year period. A single RockClime climate station was developed and used for the entire sampling area. This station was “located” at 5415 feet and “received” 14.3 inches of precipitation annually. The analysis area was divided into two soil types, sandy loam and loam. The soil type used to model an individual watershed was based on that watershed’s underlying geology. Sandy loam soils were used for watersheds in granitic geologies, and loam soils were used in watersheds in the northern Lake Helena watershed, outside of the batholith.

5.0 SEDIMENT MODELING RESULTS

This section summarizes the results of the additional sediment source assessment modules.

5.1 Remote sediment source quantification

The remote sediment source quantification of current stream conditions for the sediment impaired streams represents a refinement to the measurements and observations assembled for the original *Preliminary Source Assessment* (Appendix C), of the *Volume I – Watershed Characterization and Water Quality Status Review* (2004). The results of this current remote survey were used in conjunction with field work conducted in the summer of 2003 and the spring of 2005 to generate sediment loads and to estimate the degree of channel alterations. In many instances channel alterations, such as length of rip-rap, are underestimated due to lack of visibility on the orthophotos. See Tables 5-1 to 5-3 for the results of the aerial sediment source assessment.

The historical analysis of channel alterations along Upper Prickly Pear Creek was conducted to differentiate the effects of channel alterations due to historical placer mining from the construction of Interstate 15. The most notable channel change for this portion of Prickly Pear Creek was the replacement of channel encroachment from placer tailing piles to encroachment from the interstate and secondary roads (Table 5-4). On average, segments MT41I006_060 and MT41I006_050 had a loss of sinuosity at 9% and 8% respectively. This loss of sinuosity coincided with an average increase in channel slope of 8% and 4% for the corresponding reaches. The surveyed portions of segments MT41I006_060, MT41I006_050, and MT41I006_040 had an average gain in bankfull width of 59%, 34%, and 13%, respectively. The portion of segment MT41I006_060 surveyed had an overall loss of encroachment for both the left and right banks due to the removal of tailings piles and relocation of the channel. But both segment MT41I006_050 and the portion of MT41I006_040 surveyed had an overall increase in left and right bank encroachment due to the interstate and secondary road development. As an example, one reach of segment MT41I006_050 went from 4 road crossings in 1956 to 12 in 1995. Although channel pattern may never recover to undisturbed conditions, the riparian vegetation appears to have rebounded in many of the reaches surveyed. See Tables 5-5 to 5-7 for the results of the historical aerial assessment.

Table 5-1. Summary of Channel Changes on Upper Prickly Pear Creek since 1956

303(d) Segment	Reach_ID	Sinuosity Δ	Channel Slope Δ	Bankfull Width Δ	Left Bank Encroachment Δ*	Right Bank Encroachment Δ*
MT41I006_060	60_R5	-9%	NC	64%	0%	-100%
MT41I006_060	60_R6	-9%	8%	53%	-83%	-85%
MT41I006_060	**Average**	**-9%**	**8%**	**59%**	**-42%**	**-92%**
MT41I006_050	50_R1	-9%	10%	96%	-100%	-2%
MT41I006_050	50_R2	-25%	22%	3%	-26%	-57%
MT41I006_050	50_R3	NC	NC	43%	75%	21%
MT41I006_050	50_R4	-8%	0%	30%	1080%	67%
MT41I006_050	50_R5	10%	-17%	25%	217%	43%
MT41I006_050	50_R6	NC	NC	9%	-72%	-42%
MT41I006_050	**Average**	**-8%**	**4%**	**34%**	**195%**	**5%**
MT41I006_040	40_R1	NC	NC	49%	-50%	-48%
MT41I006_040	40_R2	NC	NC	-22%	34%	131%
MT41I006_040	40_R3	NC	NC	12%	100%	100%
MT41I006_040	**Average**	**NC**	**NC**	**13%**	**28%**	**61%**

NC = No Change

*Measures for the specified reaches on recent photos were made for all forms of encroachment, not just roads (i.e. placer tailings piles)

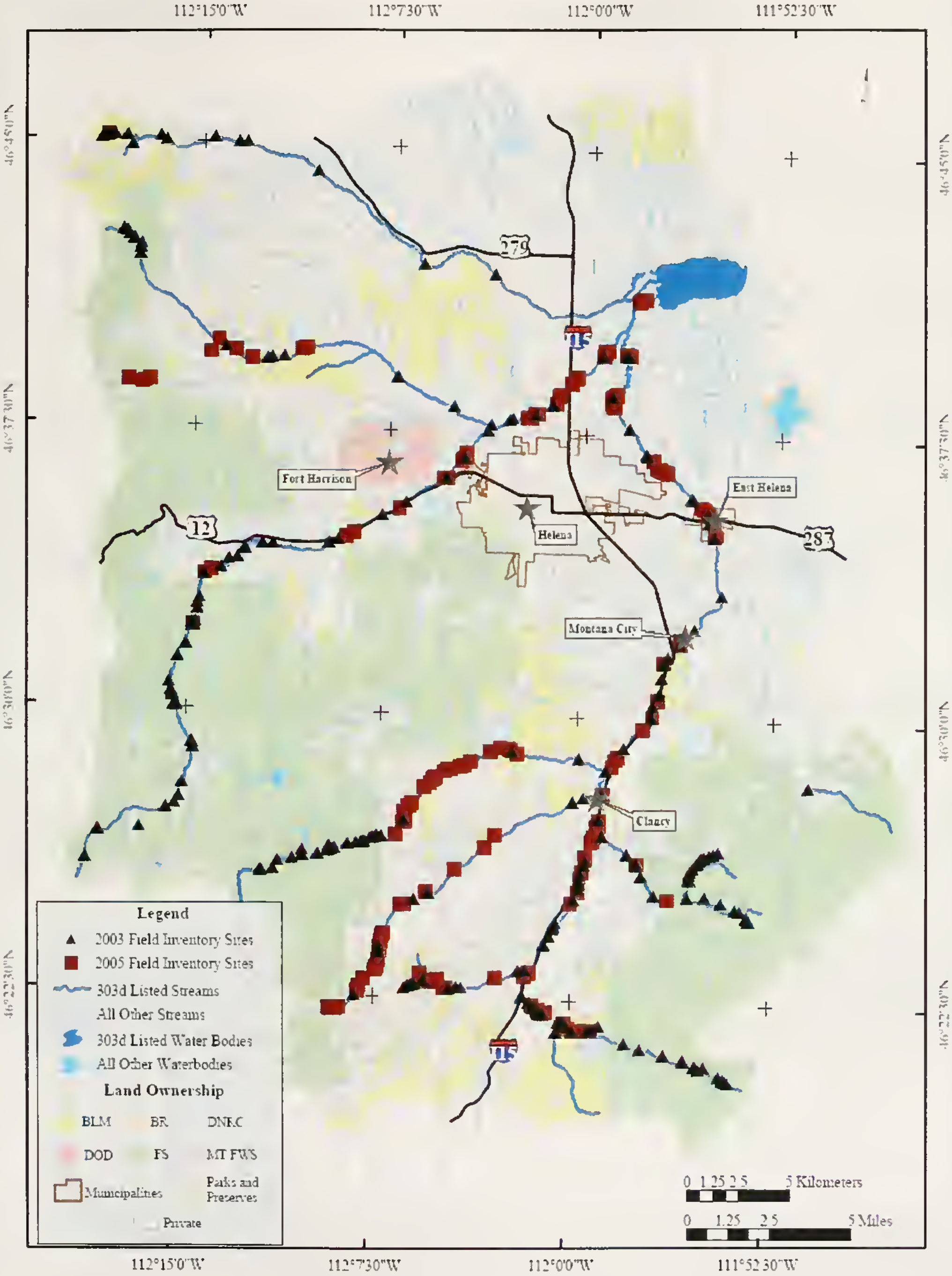


Figure 5-1. Locations of the 2003 and 2005 Field Survey Source Assessment Sites

Table 5-2. Aerial Sediment Source Assessment: 303(d) Channel Form

303(d) Segment	Photo Year & Source	Reach ID	Reach Length (ft)	Elevation Δ (ft)	Valley Length	Valley Slope	Sinuosity	Channel Slope	Bankfull Width (ft)
MT41I006_060	1998 - BW Ortho	60_R1	12880	1235	12570	9.8%	1.0	9.6%	~5
MT41I006_060	1998 - BW Ortho	60_R2	12157	665	11203	5.9%	1.1	5.5%	~10
MT41I006_060	1998 - BW Ortho	60_R3	9611	485	9172	5.3%	1.0	5.0%	~10
MT41I006_060	1995 - BW Ortho	60_R4	6014	155	5651	2.7%	1.1	2.6%	~10
MT41I006_060	1995 - BW Ortho	60_R5	1645	30	1583	1.9%	1.0	1.8%	25.0
MT41I006_060	1995 - BW Ortho	60_R6	4706	65	4489	1.4%	1.0	1.4%	26.8
MT41I006_090	1995 - BW Ortho	CRB_R1	8996	1040	8488	12.3%	1.1	11.6%	~5
MT41I006_090	1995 - BW Ortho	CRB_R2	873	45	837	5.4%	1.0	5.2%	~10
MT41I006_090	1995 - BW Ortho	CRB_R3	5056	188	4852	3.9%	1.0	3.7%	~10
MT41I006_080	1995 - BW Ortho	SPR_R1	7764	142	7372	1.9%	1.1	1.8%	~10
MT41I006_080	1995 - BW Ortho	SPR_R2	1315	35	1296	2.7%	1.0	2.7%	~10
MT41I006_050	1995 - BW Ortho	50_R1	3996	42	3829	1.1%	1.0	1.1%	23.5
MT41I006_050	1995 - BW Ortho	50_R2	16577	183	17728	1.0%	0.9	1.1%	18.5
MT41I006_050	1997 - BW Ortho	50_R3	5456	45	5364	0.8%	1.0	0.8%	18.3
MT41I006_050	1997 - BW Ortho	50_R4	4082	40	3573	1.1%	1.1	1.0%	23.2
MT41I006_050	1997 - BW Ortho	50_R5	3225	17	2998	0.6%	1.1	0.5%	19.0
MT41I006_050	1997 - BW Ortho	50_R6	3853	23	3516	0.7%	1.1	0.6%	22.3
MT41I006_100	1997 - BW Ortho	MFWS_R1	7300	690	7221	9.6%	1.0	9.5%	~10
MT41I006_100	1997 - BW Ortho	MFWS_R2	7599	477	7447	6.4%	1.0	6.3%	~10
MT41I006_180	1997 - BW Ortho	NFWS_R1	3653	495	3483	14.2%	1.0	13.6%	~5
MT41I006_180	1997 - BW Ortho	NFWS_R2	2814	185	2725	6.8%	1.0	6.6%	~5
MT41I006_180	1997 - BW Ortho	NFWS_R3	7953	567	7564	7.5%	1.1	7.1%	~10
MT41I006_180	1997 - BW Ortho	NFWS_R4	5155	200	4828	4.1%	1.1	3.9%	~15
MT41I006_110	1997 - BW Ortho	WS_R1	5704	90	4491	2.0%	1.3	1.6%	~20
MT41I006_110	1997 - BW Ortho	WS_R2	5543	88	4263	2.1%	1.3	1.6%	~20
MT41I006_110	1997 - BW Ortho	WS_R3	6572	90	5053	1.8%	1.3	1.4%	~25
MT41I006_110	1997 - BW Ortho	WS_R4	1361	10	1335	0.7%	1.0	0.7%	~15
MT41I006_120	1995 - BW Ortho	CL_R1	8671	1220	8317	14.7%	1.0	14.1%	~10
MT41I006_120	1995 - BW Ortho	CL_R2	9388	335	8519	3.9%	1.1	3.6%	~15
MT41I006_120	1995 - BW Ortho	CL_R3	4873	235	4680	5.0%	1.0	4.8%	~10

Table 5-2. Aerial Sediment Source Assessment: 303(d) Channel Form

303(d) Segment	Photo Year & Source	Reach ID	Reach Length (ft)	Elevation Δ (ft)	Valley Length	Valley Slope	Sinuosity	Channel Slope	Bankfull Width (ft)
MT41I006_120	1995 - BW Ortho	CL_R4	10634	350	9514	3.7%	1.1	3.3%	~15
MT41I006_120	1995 - BW Ortho	CL_R5	13552	235	12854	1.8%	1.1	1.7%	~20
MT41I006_120	1995 - BW Ortho	CL_R6	7154	95	6509	1.5%	1.1	1.3%	~20
MT41I006_120	1995 - BW Ortho	CL_R7	13000	195	12332	1.6%	1.1	1.5%	~20
MT41I006_120	1997 - BW Ortho	CL_R8	3522	40	2702	1.5%	1.3	1.1%	~20
MT41I006_120	1997 - BW Ortho	CL_R9	473	10	473	2.1%	1.0	2.1%	~15
MT41I006_130	1995 - BW Ortho	LG_R1	6537	540	6425	8.4%	1.0	8.3%	~5
MT41I006_130	1995 - BW Ortho	LG_R2	15415	900	13941	6.5%	1.1	5.8%	~10
MT41I006_130	1995 - BW Ortho	LG_R3	10411	410	9785	4.2%	1.1	3.9%	~10
MT41I006_130	1995 - BW Ortho	LG_R4	3824	90	3096	2.9%	1.2	2.4%	~15
MT41I006_130	1995 - BW Ortho	LG_R5	4809	205	4430	4.6%	1.1	4.3%	~15
MT41I006_130	1995 - BW Ortho	LG_R6	15931	585	14313	4.1%	1.1	3.7%	~15
MT41I006_130	1995 - BW Ortho	LG_R7	3507	80	3060	2.6%	1.1	2.3%	~20
MT41I006_130	1995 - BW Ortho	LG_R8	4485	70	4173	1.7%	1.1	1.6%	~15
MT41I006_130	1995 - BW Ortho	LG_R9	17057	130	14534	0.9%	1.2	0.8%	~20
MT41I006_040	1995 - BW Ortho/2004 C Ortho	40_R1	9307	65	8346	0.8%	1.1	0.7%	31.5
MT41I006_040	2004 C Ortho	40_R2	12238	55	11370	0.5%	1.1	0.4%	20.6
MT41I006_040	2004 C Ortho	40_R3	9908	40	8082	0.5%	1.2	0.4%	27.7
MT41I006_040	2004 C Ortho	40_R4	7641	60	7279	0.8%	1.0	0.8%	24.8
MT41I006_040	2004 C Ortho	40_R5	9220	55	7107	0.8%	1.3	0.6%	32.2
MT41I006_040	2004 C Ortho	40_R6	5667	40	5407	0.7%	1.0	0.7%	38.0
MT41I006_040	2004 C Ortho	40_R7	5371	42	4748	0.9%	1.1	0.8%	28.0
MT41I006_030	2004 C Ortho	30_R1	2235	3	1817	0.2%	1.2	0.1%	16.2
MT41I006_030	2004 C Ortho	30_R2	9244	65	8434	0.8%	1.1	0.7%	28.4
MT41I006_030	2004 C Ortho	30_R3	16236	62	10956	0.6%	1.5	0.4%	24.9
MT41I006_020	2004 C Ortho	20_R1	10860	21	5500	0.4%	2.0	0.2%	28.4
MT41I006_020	2004 C Ortho	20_R2	13928	27	7786	0.3%	1.8	0.2%	27.5
MT41I006_020	2004 C Ortho	20_R3	11297	10	8241	0.1%	1.4	0.1%	35.4
MT41I006_142	1995 - BW Ortho/2004 C Ortho	142_R1	6878	175	6395	2.7%	1.1	2.5%	~20
MT41I006_142	1995 - BW Ortho	142_R2	4774	125	4431	2.8%	1.1	2.6%	~20

Table 5-2. Aerial Sediment Source Assessment: 303(d) Channel Form

303(d) Segment	Photo Year & Source	Reach ID	Reach Length (ft)	Elevation Δ (ft)	Valley Length	Valley Slope	Sinuosity	Channel Slope	Bankfull Width (ft)
MT41I006_142	1995 - BW Ortho/2004 C Ortho	142_R3	6567	130	5734	2.3%	1.1	2.0%	~25
MT41I006_142	2004 C Ortho	142_R4	3815	75	3608	2.1%	1.1	2.0%	~25
MT41I006_142	2004 C Ortho	142_R5	7773	140	7175	2.0%	1.1	1.8%	~25
MT41I006_142	2004 C Ortho	142_R6	10915	175	9718	1.8%	1.1	1.6%	~25
MT41I006_143	2004 C Ortho	143_R1	17580	245	15874	1.5%	1.1	1.4%	~25
MT41I006_143	2004 C Ortho	143_R2	2576	35	2447	1.4%	1.1	1.4%	~25
MT41I006_143	2004 C Ortho	143_R3	9062	90	7623	1.2%	1.2	1.0%	~30
MT41I006_143	2004 C Ortho	143_R4	3813	32	3733	0.9%	1.0	0.8%	~25
MT41I006_143	2004 C Ortho	143_R5	5199	58	4569	1.3%	1.1	1.1%	~25
MT41I006_143	2004 C Ortho	143_R6	13572	109	11646	0.9%	1.2	0.8%	~25
MT41I006_143	2004 C Ortho	143_R7	12471	71	8384	0.8%	1.5	0.6%	~25
MT41I006_143	2004 C Ortho	143_R8	10850	55	7812	0.7%	1.4	0.5%	~25
MT41I006_143	2004 C Ortho	143_R9	6351	40	5131	0.8%	1.2	0.6%	~25
MT41I006_143	2004 C Ortho	143_R10	11162	35	7655	0.5%	1.5	0.3%	~25
MT41I006_220	1995 - BW Ortho	SG_R1	7719	800	7100	11.3%	1.1	10.4%	~10
MT41I006_220	1995 - BW Ortho	SG_R2	5084	380	4676	8.1%	1.1	7.5%	~10
MT41I006_220	1995 - BW Ortho	SG_R3	8445	450	7739	5.8%	1.1	5.3%	~10
MT41I006_220	2004 C Ortho	SG_R4	7980	395	7310	5.4%	1.1	4.9%	~10
MT41I006_220	2004 C Ortho	SG_R5	5745	58	4875	1.2%	1.2	1.0%	~10
MT41I006_220	2004 C Ortho	SG_R6	4234	119	3931	3.0%	1.1	2.8%	~10
MT41I006_220	2004 C Ortho	SG_R7	4546	103	4225	2.4%	1.1	2.3%	~10
MT41I006_160	2004 C Ortho	SVM_R1	5385	88	4484	2.0%	1.2	1.6%	~15
MT41I006_160	2004 C Ortho	SVM_R2	6591	87	5347	1.6%	1.2	1.3%	~20
MT41I006_160	2004 C Ortho	SVM_R3	3235	40	2661	1.5%	1.2	1.2%	~20
MT41I006_160	2004 C Ortho	SVM_R4	12624	125	8344	1.5%	1.5	1.0%	~20
MT41I006_160	2004 C Ortho	SVM_R5	8697	93	5487	1.7%	1.6	1.1%	~20
MT41I006_160	2004 C Ortho	SVM_R6	9513	84	6489	1.3%	1.5	0.9%	~20
MT41I006_160	2004 C Ortho	SVM_R7	4449	40	3861	1.0%	1.2	0.9%	~15
MT41I006_160	2004 C Ortho	SVM_R8	1958	20	1539	1.3%	1.3	1.0%	~15
MT41I006_210	1995 - BW Ortho	JF_R1	2579	335	2481	13.5%	1.0	13.0%	~5

Table 5-2. Aerial Sediment Source Assessment: 303(d) Channel Form

303(d) Segment	Photo Year & Source	Reach ID	Reach Length (ft)	Elevation Δ (ft)	Valley Length	Valley Slope	Sinuosity	Channel Slope	Bankfull Width (ft)
MT41I006_210	1995 - BW Ortho	JF_R2	1612	225	1561	14.4%	1.0	14.0%	~10
MT41I006_210	1995 - BW Ortho	JF_R3	1284	85	1146	7.4%	1.1	6.6%	~10
MT41I006_210	1995 - BW Ortho	JF_R4	1956	43	1872	2.3%	1.0	2.2%	~10

Table 5-3. Aerial Sediment Source Assessment: 303(d) Channel Alterations

303(d) Segment	Photo Year & Source	Reach ID	Length of Road w/in 100 ft of Reach (GIS, ft)	Length of Railway w/in 100 ft of Reach (GIS, ft)	Left Bank Length of Reach w/ Road Encroachment (ft)	Right Bank Length of Reach w/ Road Encroachment (ft)	Left Bank Length of RipRap (ft)	Right Bank Length of RipRap (ft)	Jettles	Dikes	Percent affected by Mining
MT41I006_060	1998 - BW Ortho	60_R1	2742.3			4520					
MT41I006_060	1998 - BW Ortho	60_R2	0.0			837					~10%
MT41I006_060	1998 - BW Ortho	60_R3	3325.7		368	4626					
MT41I006_060	1995 - BW Ortho	60_R4	2896.1			3163		60			
MT41I006_060	1995 - BW Ortho	60_R5	186.3								45%
MT41I006_060	1995 - BW Ortho	60_R6	769.7		596	579					12%
MT41I006_090	1995 - BW Ortho	CRB_R1	504.4								5%
MT41I006_090	1995 - BW Ortho	CRB_R2	681.0		873						100%
MT41I006_090	1995 - BW Ortho	CRB_R3	2731.9	199 - too high	1276						
MT41I006_080	1995 - BW Ortho	SPR_R1	579.8		659						100%
MT41I006_080	1995 - BW Ortho	SPR_R2	1328.8		976	505					41%
MT41I006_050	1995 - BW Ortho	50_R1	840.3			823		120		1	100%
MT41I006_050	1995 - BW Ortho	50_R2	12660.4		9559	1486	405				78%
MT41I006_050	1997 - BW Ortho	50_R3	6083.4	4931 hand calc	5456	3449	500	500			
MT41I006_050	1997 - BW Ortho	50_R4	2776.6		1193	1396	378	351			
MT41I006_050	1997 - BW Ortho	50_R5	3564.9	428.7	1227.	3225	2900	2900			
MT41I006_050	1997 - BW Ortho	50_R6	305.5	49.9	145	343					100%
MT41I006_100	1997 - BW Ortho	MFWS_R1	3228.6		1178	2952					23%
MT41I006_100	1997 - BW Ortho	MFWS_R2	5042.4			4519					
MT41I006_180	1997 - BW Ortho	NFWS_R1	1058.1	road probably far enough away to not impact stream except for about 550'							
MT41I006_180	1997 - BW Ortho	NFWS_R2	810.7			1367					
MT41I006_180	1997 - BW Ortho	NFWS_R3	2994.0			3782					
MT41I006_180	1997 - BW Ortho	NFWS_R4	2134.4			1210					~40%
MT41I006_110	1997 - BW Ortho	WS_R1	560.2								~40%
MT41I006_110	1997 - BW Ortho	WS_R2	1918.4			686					
MT41I006_110	1997 - BW Ortho	WS_R3	1215.0								
MT41I006_110	1997 - BW Ortho	WS_R4	1424.2		215	1186	135	135			~50%
MT41I006_120	1995 - BW Ortho	CL_R1	4944.6		4499						13%
MT41I006_120	1995 - BW Ortho	CL_R2	2178.1		360	1109	105	105			~20%
MT41I006_120	1995 - BW Ortho	CL_R3	3539.4			1542					~90%
MT41I006_120	1995 - BW Ortho	CL_R4	2974.3		386						13%
MT41I006_120	1995 - BW Ortho	CL_R5	2066.8								~90%
MT41I006_120	1995 - BW Ortho	CL_R6	801.9								~10%
MT41I006_120	1995 - BW Ortho	CL_R7	306.2		1009						~95%
MT41I006_120	1997 - BW Ortho	CL_R8	312.0	52.7							

Table 5-3. Aerial Sediment Source Assessment: 303(d) Channel Alterations

303(d) Segment	Photo Year & Source	Reach ID	Length of Road w/in 100 ft of Reach (GIS, ft)	Length of Railway w/in 100 ft of Reach (GIS, ft)	Left Bank Length of Reach w/ Road Encroachment (ft)	Right Bank Length of Reach w/ Road Encroachment (ft)	Left Bank Length of RipRap (ft)	Right Bank Length of RipRap (ft)	Jetties	Dikes	Percent affected by Mining
MT41I006_120	1997 - BW Ortho	CL_R9	527.6	492.4		473					
MT41I006_130	1995 - BW Ortho	LG_R1	0.0								
MT41I006_130	1995 - BW Ortho	LG_R2	1357.4		436						~25%
MT41I006_130	1995 - BW Ortho	LG_R3	1249.1								~35%
MT41I006_130	1995 - BW Ortho	LG_R4	1035.6								~30%
MT41I006_130	1995 - BW Ortho	LG_R5	1443.5		537	1003		78			~10%
MT41I006_130	1995 - BW Ortho	LG_R6	8545.9		7763						~5%
MT41I006_130	1995 - BW Ortho	LG_R7	199.7								
MT41I006_130	1995 - BW Ortho	LG_R8	2130.1		664	469	40	100			
MT41I006_130	1995 - BW Ortho	LG_R9	1704.9				90	90			
MT41I006_040	1995 - BW Ortho/2004 C Ortho	40_R1	1912.8	2345.4	3223	1829	525	901			~35%
MT41I006_040	2004 C Ortho	40_R2	5677.2	5445.4	4863	6021	4958	5392			
MT41I006_040	2004 C Ortho	40_R3	1017.9	941.8	785	350	1427	430			~45%
MT41I006_040	2004 C Ortho	40_R4	1740.6	955.4	1226	1829	581	581			~80%
MT41I006_040	2004 C Ortho	40_R5	0.0	1610.9	363	998	193	317			~40%
MT41I006_040	2004 C Ortho	40_R6	160.6	430.9	100	825	939	284		2	100%
MT41I006_040	2004 C Ortho	40_R7	1257.1	97.8	625	625	172	178		1	
MT41I006_030	2004 C Ortho	30_R1	483.4				141	111			
MT41I006_030	2004 C Ortho	30_R2	203.3		100	100				1	
MT41I006_030	2004 C Ortho	30_R3	1691.0		718	100	401	75		1	
MT41I006_020	2004 C Ortho	20_R1	248.1				247	210			
MT41I006_020	2004 C Ortho	20_R2	1325.7		653	888	800	1024			
MT41I006_020	2004 C Ortho	20_R3	0.0								
MT41I006_142	1995 - BW Ortho/2004 C Ortho	142_R1	1962.1		559	2265					12%
MT41I006_142	1995 - BW Ortho	142_R2	1325.9		1184	1738					~30%
MT41I006_142	1995 - BW Ortho/2004 C Ortho	142_R3	750.4		841	367					~10%
MT41I006_142	2004 C Ortho	142_R4	2210.2		80	1571					
MT41I006_142	2004 C Ortho	142_R5	4950.2		1481	1824					~5%
MT41I006_142	2004 C Ortho	142_R6	3231.8		527	2290					
MT41I006_143	2004 C Ortho	143_R1	862.5								
MT41I006_143	2004 C Ortho	143_R2	475.7		158	2254				1	

Table 5-3. Aerial Sediment Source Assessment: 303(d) Channel Alterations

303(d) Segment	Photo Year & Source	Reach ID	Length of Road w/in 100 ft of Reach (GIS, ft)	Length of Railway w/in 100 ft of Reach (GIS, ft)	Left Bank Length of Reach w/ Road Encroachment (ft)	Right Bank Length of Reach w/ Road Encroachment (ft)	Left Bank Length of RipRap (ft)	Right Bank Length of RipRap (ft)	Jettles	Dikes	Percent affected by Mining
MT41I006_143	2004 C Ortho	143_R3	816.6		308	962					
MT41I006_143	2004 C Ortho	143_R4	303.2			3813					
MT41I006_143	2004 C Ortho	143_R5	1313.3		252		450				
MT41I006_143	2004 C Ortho	143_R6	1153.5	529.2							
MT41I006_143	2004 C Ortho	143_R7	219.7				380	260	1		
MT41I006_143	2004 C Ortho	143_R8	1642.0		670	1704	225 (surveyed)				
MT41I006_143	2004 C Ortho	143_R9	0.0								
MT41I006_143	2004 C Ortho	143_R10	235.1								
MT41I006_220	1995 - BW Ortho	SG_R1	3568.7		854	879					
MT41I006_220	1995 - BW Ortho	SG_R2	0.0								20%
MT41I006_220	1995 - BW Ortho	SG_R3	1139.4		1042						
MT41I006_220	2004 C Ortho	SG_R4	2441.9			150					~3%
MT41I006_220	2004 C Ortho	SG_R5	1032.6		216	133					~3%
MT41I006_220	2004 C Ortho	SG_R6	4028.3		1081	101					
MT41I006_220	2004 C Ortho	SG_R7	3340.9	102.3	1083	118					
MT41I006_160	2004 C Ortho	SVM_R1	0.0	422.1	392	131					14%
MT41I006_160	2004 C Ortho	SVM_R2	0.0	766.0	1426	71					
MT41I006_160	2004 C Ortho	SVM_R3	0.0	915.7		313					
MT41I006_160	2004 C Ortho	SVM_R4	373.9	2586.8	105	1045					
MT41I006_160	2004 C Ortho	SVM_R5	994.9	360.6		190					
MT41I006_160	2004 C Ortho	SVM_R6	188.0		119	58				1	~10%
MT41I006_160	2004 C Ortho	SVM_R7	0.0								
MT41I006_160	2004 C Ortho	SVM_R8	0.0	215.8	125	125					
MT41I006_210	1995 - BW Ortho	JF_R1	3224.5		2216	832					6%
MT41I006_210	1995 - BW Ortho	JF_R2	944.8		72	342					
MT41I006_210	1995 - BW Ortho	JF_R3	693.8								
MT41I006_210	1995 - BW Ortho	JF_R4	208.1		150	150					

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_060	1998 - BW Ortho	60_R1	forest - recreation/habitat	Evergreen Forest	dense conifer forest, forest road is probably the only man caused sediment source - more ATV trails visible than in GIS layer
MT41I006_060	1998 - BW Ortho	60_R2	forest - recreation/habitat, some private houses near end of reach	mostly Evergreen Forest with some Grassland area near stream	dense conifer forest with some wetland areas in stream bottom, forest road and possibly development near end of reach man caused sediment sources, HNF documented some incision from historic mining, 1 road crossing
MT41I006_060	1998 - BW Ortho	60_R3	forest/private houses	Evergreen Forest	conifer forest with land ownership change to private, dispersed housing, 3 road crossings, road encroaches in narrow valley opening
MT41I006_060	1995 - BW Ortho	60_R4	forest/private houses	Evergreen Forest transitioning to Grassland	dispersed housing, 3 road crossings, road encroaches in narrow valley opening
MT41I006_060	1995 - BW Ortho	60_R5	pasture	Grassland	major alterations for dredge boat operation (40% of reach), braiding/split channel near end of reach, 1 road crossing
MT41I006_060	1995 - BW Ortho	60_R6	transportation corridor	Grassland/Wetland / Evergreen Forest	channel has been moved from 1956 location towards LB, beaver ponds/wetland area surround stream, dense riparian vegetation, Road crossings 2 (I15 and Jefferson City entry)
MT41I006_090	1995 - BW Ortho	CRB_R1	occasional pasture	Grassland	intermittent stream, not much for man-caused sediment sources, some small mine spoil piles proximal to stream (Monte Christo, Horseshoe Claim, Chalcopyrite Mine) , 2 road crossings (private low use road)
MT41I006_090	1995 - BW Ortho	CRB_R2	mine reclamation	Grassland	mine reclamation from Bertha mine has left riparian area barren, straightened channel, and armored banks (100% of reach altered), numerous road sediment delivery sites to upstream tributaries, H.P. mine: Alta in tributary HW
MT41I006_090	1995 - BW Ortho	CRB_R3	occasional pasture with small town at end of stream	Grassland	riparian area continues to be barren, some road encroachment, channelization in town of Corbin (15% of reach), 4 road crossings (2 driveways)
MT41I006_080	1995 - BW Ortho	SPR_R1	pasture, some dispersed housing	Grassland	mine reclamation from Corbin Flats mine has left riparian area barren and straightened channel into virtually a ditch (90% of reach)
MT41I006_080	1995 - BW Ortho	SPR_R2	townsite, some pasture at beginning of reach	Grassland	reach is 100% channelized for flow through Jefferson City, 3 road crossings
MT41I006_050	1995 - BW Ortho	50_R1	transportation corridor	mostly Grassland, some Evergreen Forest and Wetland	reach is staring to gain some sinuosity, bermed at end of reach for flow through culvert under I15, dense riparian vegetation near end of reach, about 80% of reach still straight from channelization associated with placer mining/highway development

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_050	1995 - BW Ortho	50_R2	transportation corridor	mostly Grassland, some Evergreen Forest and Shrubland	virtually entire reach is channelized, rip rap probably an underestimate, some areas of meander bends with gravel bar deposits/split channel, 12 roads crossings (1- I15, others mostly driveways), reach confined between highway/frontage road and terrace (RB), minor road encroachment on RB, end of reach sinuous
MT41I006_050	1997 - BW Ortho	50_R3	transportation corridor	Com/Ind/Trans, Evergreen Forest, Grassland	entire reach confined between RR bed and I15, 100% channelized, lots of riprap documented in the field (amount calculated probably underestimate), 2 road crossings (I15), road encroachment for LB is mainly from old RR bed
MT41I006_050	1997 - BW Ortho	50_R4	transportation corridor/campground	Com/Ind/Trans, Evergreen Forest, Grassland/Shrubland	stream flowing between I15 and frontage road, "relatively unconfined" - 35% channelized -allowed to meander in sections, but campground developed on banks with riprap
MT41I006_050	1997 - BW Ortho	50_R5	transportation corridor/townsite	mostly Grassland, some Shrubland	stream is virtually a straight line, 100% channelized, between I15 and frontage/RR in town of Clancy, Clancy Creek enters here, only bends are for road crossings (3)
MT41I006_050	1997 - BW Ortho	50_R6	wetland/lumber yard	mostly Grassland, some Evergreen Forest and Shrubland	beginning and end of reach have been straightened (placer tailings as levees) 70% channelized, middle section is fairly sinuous, dense riparian vegetation especially near end of reach , some encroachment from lumber mill, 1 road crossing
MT41I006_100	1997 - BW Ortho	MFWS_R1	abandoned mines in HNF/old timber harvest on private inholdings in steep slope above	mostly Evergreen Forest	numerous abandoned mine sites within stream corridor and of tributaries (2 HP: Solar Silver and MFWS, White Pine area documented by HNF as problem), tailings preventing growth of vegetation in sections and identified as a sediment source, road encroaches on stream -4 road crossings (more shown than in GIS layer)/old timber harvest on private land in steep slopes above stream
MT41I006_100	1997 - BW Ortho	MFWS_R2	HNF rec/roaded	mostly Evergreen Forest	road encroaches on stream for most of reach - at least 2 road crossings (more shown than in GIS layer), breached mining dam documented by HNF
MT41I006_180	1997 - BW Ortho	NFWS_R1	HNF rec/roaded	mostly Evergreen Forest, some Grassland	reach was mostly burned over in 1988 fire, few older trees left in riparian corridor, 1 road crossing, mostly natural sediment sources, 1 abandoned mine shown -Willard Group (underground)
MT41I006_180	1997 - BW Ortho	NFWS_R2	rural housing (1)/transportation corridor	mostly Grassland/Shrubland, some Deciduous Forest	stream probably is intermittent until joining tributary at major aspect change, encroached by road for about half of reach length, road sediment delivery sites documented by HNF, small harvest on private property
MT41I006_180	1997 - BW Ortho	NFWS_R3	HNF rec/roaded	Evergreen Forest	road encroaches on stream for most of reach - 1 road crossing, numerous road sediment delivery sites documented by HNF

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_180	1997 - BW Ortho	NFWS_ R4	HNF rec/roaded, rural housing (1)	mostly Evergreen Forest, with Grassland near mouth	stream transforms from somewhat confined to fairly unconfined at mouth, some road encroachment, evidence of placer mining and minor grazing impacts observed in field
MT41I006_110	1997 - BW Ortho	WS_R1	rural housing	mostly Grassland, some Evergreen Forest, Wetland, and Shrubland	beginning of reach shows signs from placer mining with raw banks/tailing levees and areas of multiple channels, poor grazing practices and confined livestock area observed in field for about 1st half of reach, 3 road crossings -problem culvert documented at Woodland Park Loop (SF WS no roads)
MT41I006_110	1997 - BW Ortho	WS_R2	rural housing (smaller lots than reach 1)	mostly Grassland with Wetland, some Evergreen Forest and Shrubland	fairly dense riparian corridor interrupted at road crossings (at least 4), small section where mowing to stream edge, abandoned mine - Warm Springs Lode shown close to stream near end of reach
MT41I006_110	1997 - BW Ortho	WS_R3	rural housing	mostly Grassland, some Shrubland	fairly dense riparian corridor interrupted at road crossings (at least 3), poor grazing practices observed in field, Hot Springs near end of reach
MT41I006_110	1997 - BW Ortho	WS_R4	transportation corridor/nursing home	mostly Grassland, some Evergreen Forest, Wetland, and Shrubland	100% channelized section, stream is completely straightened, input from hot springs here, dense willow trees lining banks for most of reach, 2 road crossings, high priority abandoned mine site near end of reach - Alhambra Hot Springs
MT41I006_120	1995 - BW Ortho	CL_R1	HNF rec/roaded	mostly Evergreen Forest, some Grassland	numerous abandoned mine sites within stream corridor and of tributaries (1 HP: Crawley Camp), 3 spoils piles within or adjacent to stream are possible sediment sources, road encroaches on stream in areas some documented with GPS -3 road crossings/main road up drainage is not shown in GIS layer
MT41I006_120	1995 - BW Ortho	CL_R2	private lands with grazing/logging	mostly Grassland, some Evergreen Forest and Shrubland	road encroaches on stream in sections (1 crossing), beaver/wetland complex area at confluence with Kady Gulch - sinuosity/channel parameters not applicable, entire reach was probably once a beaver/wetland complex (evidence in field of old dams), mine spoil piles contributing sediment to stream near end of reach (GPS site - Ariadne Mine), recent timber harvest observed in field adjacent to riparian corridor on private lands -grazing also observed, reach ends at downstream boundary of Gregory Mine Site (H.P.)
MT41I006_120	1995 - BW Ortho	CL_R3	private lands with grazing/hist. mine areas	mostly Evergreen Forest, some Shrubland and Grassland	reach is downcut into confined valley bottom, evidence of old placer mining/altered stream course, county road is a problem in this reach - road blowouts and sediment delivery sites documented in field

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_120	1995 - BW Ortho	CL_R4	private lands with grazing/haying	mostly Grassland, some Evergreen Forest and Shrubland	stream relatively unconfined for most of reach, one section of placer mining (~1354'), grazing causing bank erosion observed in beginning of reach and mid section of reach (BEHI), haying in open meadows, evidence of old beaver dams, few sites where roads delivers sediment (1 crossing - priv.), end of reach property with concentrated farm activities - foul and livestock with ponds/Quartz Creek enters here - harvests visible and H.P. ab. mine: Argentine
MT41I006_120	1995 - BW Ortho	CL_R5	private lands old placer piles, some rural subdivision development	mostly Grassland, some Evergreen Forest and Shrubland	about 90% of reach flows within large 'placer terraces' that contribute sediment in some sections (Clancy Creek Placer, steep slopes make it difficult for vegetation to re-establish), stream re-establishing sinuosity and stabilized banks in sections where viewed, end of reach BLM land -impoundment with unknown purpose, 2 road crossings (1 documented sediment delivery site)
MT41I006_120	1995 - BW Ortho	CL_R6	private lands with grazing/haying	mostly Grassland, some Evergreen Forest and Shrubland	stream relatively unconfined for most of reach, grazing causing bank erosion observed within reach (BEHI), haying in open meadows, evidence of old beaver dams, road is not a sediment source in reach
MT41I006_120	1995 - BW Ortho	CL_R7	private lands old placer piles, some rural subdivision development/grazing	mostly Grassland and Evergreen Forest, some Shrubland	about 95% of reach flows within large 'placer terraces' that may contribute sediment in some sections - coarser substrate than upper placer reach (Clancy Creek Placer cont.?), 2 road crossings, grazing observed in field
MT41I006_120	1997 - BW Ortho	CL_R8	townsite, some pasture/hay fields	mostly Grassland	stream is relatively unconfined and sinuous, school track near floodplain and haying downstream, 1 road crossing in town
MT41I006_120	1997 - BW Ortho	CL_R9	transportation corridor	Grassland	100% channelized section, stream is completely straightened
MT41I006_130	1995 - BW Ortho	LG_R1	HNF rec	Evergreen Forest	apparently pristine section, no sources observed
MT41I006_130	1995 - BW Ortho	LG_R2	HNF rec/roaded/mine sites	Evergreen Forest with Transitional Area	Lots of disturbance in reach spanning from mining dams and rock walls lining stream banks to timber harvest and associated road network (all on HNF), 3 road crossings (1 not in GIS layer), Frohner Basin drainage enters here with 4 HP mines: Frohner (2 sites), General Grant, and Nellie Grant
MT41I006_130	1995 - BW Ortho	LG_R3	HNF rec/private inholding (extraction)	Grassland and Evergreen Forest	stream flows through private inholding within HNF, timber harvest along private boundary, 6 road crossings documented by the HNF (not in GIS), mining and grazing impacts recorded by HNF

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_130	1995 - BW Ortho	LG_R4	private housing	mostly Evergreen Forest, some Shrubland and Grassland	first half of reach is a wetland complex, second half of stream downcuts through canyon, 4 road crossings
MT41I006_130	1995 - BW Ortho	LG_R5	transportation corridor in forest setting	mostly Evergreen Forest, some Grassland and Shrubland	roads are problematic sediment source from this reach practically to mouth - numerous delivery sites documented in field even where not encroaching on floodplain, sediment delivery from Corral Gulch Rd, perched culvert at Corral Gulch entry, 1 road crossing
MT41I006_130	1995 - BW Ortho	LG_R6	transportation corridor in forest setting/rural home sites near end of reach	mostly Evergreen Forest, some Grassland and Shrubland	roads are problematic sediment source - numerous delivery sites documented in field even where not encroaching on floodplain, private road not in GIS is a big sediment source in few areas, timber harvest in riparian area, at least 5 road crossings
MT41I006_130	1995 - BW Ortho	LG_R7	rural housing/pasture	mostly Grassland and Evergreen Forest	stream pulls away from road here mostly unconfined in meadow, some delivery at road crossings, grazing impacts, at least 3 road crossings, sediment input from new development draining to stream
MT41I006_130	1995 - BW Ortho	LG_R8	transportation corridor in forest setting	mostly Evergreen Forest, some Grassland and Wetland	stream is more confined again with road sediment inputs (2 crossings), beaver dams in one section with massive amount of sands trapped behind dam
MT41I006_130	1995 - BW Ortho	LG_R9	meadow with haying/grazing and rural housing	mostly Grassland, some Evergreen Forest and Shrubland	reach is relatively unconfined in meadow, variable riparian buffer widths, some areas of beaver dams, irrigation diversions, straightened near end of reach (1650'), 6 road crossings (more than in GIS)
MT41I006_040	1995 - BW Ortho/2004 C Ortho	40_R1	transportation corridor (I15 and RR, frontage roads)	mostly Evergreen Forest with Grassland, some Wetland and Shrubland	stream is straightened (90% channelized) and confined mainly by railroad (lumber area and pond near end of reach), fairly stable streambanks viewed in field, but riparian vegetation density is variable, gaining sinuosity where not encroached by roads, detached point bars and split channel visible in areas, 2 crossings (1 RR), some of encroachment from old RR bed
MT41I006_040	2004 C Ortho	40_R2	transportation corridor (I15 and RR, frontage roads)/subdivisions upslope	Grasslands adjacent to Transportation Corridor and Shrubland	major channelized section (95%), stream is heavily rip-rapped and downcut, very narrow corridor for shade producing vegetation, stream is trying to gain sinuosity, 4 road crossings (1RR), some of encroachment from old RR bed

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_040	2004 C Ortho	40_R3	wetland riparian area surrounded by rural homesites/transportation lanes	mostly Wetland	reach is relatively unconfined, fairly dense riparian buffer, stream widens, 1 irrigation diversion, straightened near end of reach probably placered (4180') 45% channelized, 4 road crossings (1 RR, 1 I15), old RR bed with some encroachment
MT41I006_040	2004 C Ortho	40_R4	wetland riparian area surrounded by transportation lanes/Ash Grove roadside park on RB	mostly Wetland	stream has been straightened probably by construction of railroad and placer mining (95% channelized), confined between railroad and highway, 2 road crossings (1hwy) and 1 footbridge, encroachment mostly from secondary roads not in GIS
MT41I006_040	2004 C Ortho	40_R5	wetland riparian area surrounded by transportation lanes/agriculture near end of reach	mostly Wetland, some Grassland and Deciduous Forest	stream gains sinuosity but still straightened in sections by railroad and probably for agricultural use or ASARCO, areas of split channels and detached point bars, very poor density of riparian vegetation around agricultural operation, 2 crossings (RR), sections where beaver dams have been removed, encroachment from RR bed
MT41I006_040	2004 C Ortho	40_R6	mostly Wetland, adjacent to defunct smelting operation	Wetland and Commercial/Industrial/Transportation	channel has been completely altered for ASARCO operation and was likely moved further East of original channel location, dam on segment as well as large slag piles that lose rubble to stream, flow leaves channel near beginning to supply cooling pond, 736' of slag = rip-rap on LB, 1 road crossing, large beaver dam viewed in field below dam, encroachment from RR bed and road crossing
MT41I006_040	2004 C Ortho	40_R7	townsite and agricultural fields after town	Low Intensity Residential, Wetland and Grassland	channel flows through E. Helena and is mostly leveed in town, irrigation diversion before end of reach and channel is split just before end of reach (for flood control?) about 60% channelized, 4 road crossings (1 RR, 1 Hwy)
MT41I006_030	2004 C Ortho	30_R1	agricultural farmstead	Grasslands	altered reach, at least 2 channels, measured channel which holds flow for most of year (LB), may be forced to flow in LB channel for irrigation diversion, 60% channelized, 2 road crossings (1 driveway, 1 Hwy), reach ends at irrigation diversion
MT41I006_030	2004 C Ortho	30_R2	agriculture and gravel pit to RB (open water assoc)	Grasslands and Pasture with Quarry on RB	altered reach that has been straightened and leveed in many areas with almost total removal of riparian vegetation, 95% channelized, many gravel bar deposits, HVID canal crosses stream here at siphon, gravel pit operations mainly on RB but looks like older pits on LB as well, 2 road crossings (1 Hwy), reach ends at Canyon Ferry Road

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_030	2004 C Ortho	30_R3	agriculture and rural homesites	Grasslands and Pasture with some Deciduous Forest	reach starts to gain sinuosity with 'less' disturbance in riparian area, lots of deposition visible in reach with channel splitting in many areas, bank erosion problematic for ~25% of reach, 3 road crossings (2 Hwy), 'Stanisfield Lake' wetland to RB near end of reach, 2 irrigation drains enter reach after sample site (appear to lower water table -begin in fields), reach ends at WWTP discharge
MT41I006_020	2004 C Ortho	20_R1	agriculture and rural homesites	Grasslands	reach maintains sinuosity but with notable disturbance in riparian area, bank erosion problematic for ~45% of reach, lots of deposition visible in reach with channel splitting in many areas, 1 road crossing - 4 secondary crossings (bridges), many areas of potential non-point nutrient sources adjacent to stream, 3 flow inputs to stream (Stanisfield Lake drainage, a spring creek that flows through a confined pasture area, irrigation drains/lateral), reach ends at irrigation inflow
MT41I006_020	2004 C Ortho	20_R2	agriculture and rural homesites/Police training academy	Grasslands and Pasture with Crops adjacent	reach maintains sinuosity and disturbance in riparian area continues, deposition still visible in reach, bank erosion problematic for ~30% of reach, 3 road crossings, some areas of potential non-point nutrient sources adjacent to stream, inflow from irrigation lateral and Tenmile Creek, reach ends at Tenmile Creek, about 15% of reach channelized for Sierra Rd crossing and Police Academy, sewage lagoons at Police Academy
MT41I006_020	2004 C Ortho	20_R3	agriculture with 1 rural homesite	Grasslands, some Crops adjacent and Wetland near lake	reach less sinuous and wider from Tenmile inflow, very little riparian vegetation, bank erosion problematic for ~30% of reach, deposition visible in reach, 2 road crossings (secondary), reach ends at Lake Helena, about 20% of reach channelized to avoid irrigation canal
MT41I006_142	1995 - BW Ortho/2004 C Ortho	142_R1	townsite/transportation corridor within forest	Evergreen Forest with some Grassland and Shrubland	reach begins at City's water diversion structure, loss of water likely to affect water quality and sediment transport, encroached by road in areas, high priority AB mine sites close to stream: Valley Forge/Susie, drainage from Upper Valley Forge would enter in this reach, clearing of forest visible for Ab mine - Lee Mtn., 1 road crossing (secondary rd), about 35% channelized for diversion and flow through Rimini
MT41I006_142	1995 - BW Ortho	142_R2	HNF rec/roaded/mine sites	Evergreen Forest	reach surrounded by forest but still encroached by road, many sediment delivery sites documented by the HNF as well as incision from historical mining, potentially 2 road crossings (1 Minnehaha Ck, 1 not in GIS - old mining road?)
MT41I006_142	1995 - BW Ortho/2004 C Ortho	142_R3	HNF rec/roaded (campground)	Evergreen Forest with some Grasslands and Shrubland	reach continues to be encroached by road in areas, valley bottom is wider than upper reaches and channel splits in a few areas, HNF documented channelization from hist. mining, 2 road crossings (main Rimini Rd)

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_142	2004 C Ortho	142_R4	HNF rec/roaded	Evergreen Forest	reach is confined and encroached by Rimini road in areas, HNF documented road sediment delivery site, 1 road crossing (cmpgrd), about 40% channelized for Rimini Road
MT41I006_142	2004 C Ortho	142_R5	transportation corridor/rural homes	Grasslands at base of Evergreen Forest	stream continues to be encroached by road in areas with exposed banks visible where encroachment is severe, valley bottom widens again, 3 road crossings (1 Rimini Rd), sediment delivery sites documented by HNF, about 30% channelized for Rimini Road
MT41I006_142	2004 C Ortho	142_R6	transportation corridor/rural homes	Grasslands, Evergreen Forest, and Shrubland	stream continues to be encroached by road in areas with exposed banks visible where encroachment is severe, transitional reach from forest to wider valley bottom opening - appears to gain flow where valley opens, 7 road crossings (1 Rimini Rd), sediment delivery sites documented by HNF and L&W, about 20% channelized for Rimini Road
MT41I006_143	2004 C Ortho	143_R1	agriculture and rural homesites	Pasture Hay, Grasslands, Wetland and some Crops	stream pulls away from road and riparian area changes to cottonwoods (where present), predominantly agricultural area with rural homes, riparian grazing observed in field and gravel pit operation near beginning of reach to RB, exposed banks visible and bank erosion likely an issue (~50% of reach), at least 3 animal feedlots located close to stream, approximately 5 irrigation diversions and 2 return flow canals, 5 road crossings (mostly secondary roads), probably channelized for irrigation purposes would expect stream to be more sinuous
MT41I006_143	2004 C Ortho	143_R2	transportation corridor/rural homes	Grasslands and Pasture Hay	short reach 100% channelized by Hwy 12 (GIS rd layer does not capture full extent), large wooded dike/dam observed for irrigation diversion, grazing observed
MT41I006_143	2004 C Ortho	143_R3	agricultural/rural homes	Pasture Hay, Wetland and LowIntensity Residential	reach mostly away from Hwy 12, meanders but cutoff observed in irrigated fields (forced?), beginning of reach flows through irrigated fields where grazing and bank erosion was observed (20% of reach), 1 diversion and 1 return flow, health of riparian vegetation variable with patches where absent in irrigated fields, mowing to edge of stream in Blue Cloud subdivision (end of reach), 2 road crossings, encroached by Hwy12 somewhat near end of reach, about 30% channelized from irrigation/hay fields and Hwy 12
MT41I006_143	2004 C Ortho	143_R4	transportation corridor/future rural homes/club	Grasslands and Wetland adjacent to Commercial/Industrial/Transportation	another short reach 100% channelized by Hwy 12 (GIS rd layer does not capture full extent), Broadwater Athletic Club adjacent to stream and observed lots for development just upstream (both LB), 1 road crossing, much of the stream appears to have levees on both banks from this point through much of the valley (to I15) - alters expected W/D ratio and entrenchment

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_143	2004 C Ortho	143_R5	rural homes/state nursery (defunct?)	Grasslands and Wetland adjacent to Commercial/Industrial/Transportation	reach pulls away from Hwy 12 again, but levees are present limiting stream's course, state nursery present here, riparian corridor fairly healthy not much for bank erosion with levees present, some rip-rap at house/pool close to stream and where road close to stream, 3 road crossings, levees channelize about 85% or more of reach
MT41I006_143	2004 C Ortho	143_R6	rural homes - subdivision/golf course	Grasslands, Wetland, and Recreational Grasses adjacent to Commercial/Industrial/Transportation, Crops and Low Intensity Residential	stream transitioning from mostly rural landuses to some urban influences with golf course and increasing housing density, rural land uses still present, levees observed along most of reach surveyed with minimal opportunity for bank erosion - probably about 80% or more of reach with levees, Schatt's diversion takes off at beginning of reach, fairly healthy riparian corridor with cottonwoods and willows present, 4 road crossings (1 RR) and 4 golf cart crossings (1 is ford?)
MT41I006_143	2004 C Ortho	143_R7	agricultural/rural homes	Wetland surrounded by Pasture/Hay and Crops	fairly unconfined reach surrounded by predominantly agricultural land uses, areas of riparian vegetation removal likely causing problems for bank erosion for at least 20% of reach, Sevenmile enters near beginning of reach just after meander cutoff (natural?), levees not as prominent, bank erosion and areas of concrete rip-rap observed in 2003 and 2005 survey, Spring Creek also enters here near end of reach (West side City of Helena Stormwater discharge enters Spring Creek) Spring Creek is channelized for irrigation use as well as to fill pond near Tenmile Ck (RB), 1 road crossing, reach ends at HVID canal siphon, 1 jetty for 1921 diversion, at least 2 irrigation diversions, about 40% of reach or more probably channelized for irrigation/hay practices
MT41I006_143	2004 C Ortho	143_R8	agricultural/subdivisions	Grasslands adjacent to Low Intensity Residential, Crops, and Commercial/Industrial/Transportation	most of reach appears to have been channelized and leveed (70% or more), areas of exposed banks likely causing problems for bank erosion for at least 15% of reach, notable subdivisions in lands just upslope from stream corridor but fair amount of hay fields/rural land use along stream, 4 road crossings including I15, appears to be an HVID canal spillway at beginning of reach where siphon travels under stream u/s of McHugh Ln, stormwater runoff from Tenmile Creek Estates appears to be channelized (2 'canals') to flow into creek and captured for irrigation diversion just u/s of I15 crossing

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_143	2004 C Ortho	143_R9	mostly agricultural/subdivision to South	Deciduous Forest adjacent to Crops and Low Intensity Residential	best potential for reference reach in valley segment surveyed, relatively unconfined with cottonwoods, fish habitat structure present but grazing management practices needed and lack of summer flows problematic, at least 1 irrigation diversion, bank erosion problematic for about 10% of reach, about 30% of reach probably channelized for irrigation/hay practices
MT41I006_143	2004 C Ortho	143_R10	mostly agricultural/with few rural homes	Grasslands and Crops	reach ends at Prickly Pear Creek, lack of riparian vegetation notable from upstream reach, 2 road crossings, encroachment noticeable from private driveway, beaver dam observed in field as well as decadent and dying cottonwoods, HVID lateral spillway just after Sierra Rd, animal confinement lots near stream by ranch house, bank failure notable in field affects ~45% of reach, about 40% of reach or more probably channelized for irrigation/hay practices
MT41I006_220	1995 - BW Ortho	SG_R1	HNF rec/roaded	mostly Evergreen Forest, some Shrubland and Grassland	steep reach near old harvest units with at least 5 road crossings from harvest roads (more than shown in GIS), grazing impacts - road sediment delivery sites and a mine dump documented by HNF, stream is probably intermittent for upper 1/2 of reach, reach ends at tributary confluence
MT41I006_220	1995 - BW Ortho	SG_R2	HNF rec	mostly Evergreen Forest, some Shrubland	steam continues along steep valley bottom slightly less confined, dense riparian vegetation, HNF documented channel alterations from placer mining - stream incised but banks are vegetated
MT41I006_220	1995 - BW Ortho	SG_R3	probably seasonal grazing	mostly Evergreen Forest with some Wetlands	reach leaves HNF, few sources observable other than possibly some road sediment input, reach ends at road crossing below confluence with East Skelly Gulch, possible grazing impacts, dense riparian vegetation, up to 3 road crossings and some encroachment from secondary roads not in GIS layer
MT41I006_220	2004 C Ortho	SG_R4	probably seasonal grazing and low density(very) rural residential	mostly Evergreen Forest, some Shrubland	dense riparian vegetation with more opening of valley bottom and wetlands - probably a few beaver dams present, possible grazing impacts, some natural terrace erosion observed in field, RB road is well above stream to not be a sediment source for much of length (GIS overestimate), much of land is subdivided and currently for sale, reach ends at road crossing- 2 road crossings (incl. stream ford at end of reach), extreme close-up reveals that stream is more sinuous than able to be digitized, old mine shaft near end of reach and some placer piles (vegetated) visible in field - many prospects visible on topos in uplands near end of reach

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_220	2004 C Ortho	SG_R5	wetlands surrounded by low density rural residential	Wetland adjacent to Evergreen Forest and shrubland	dense riparian vegetation with a large beaver complex for much of reach (channel measures difficult to apply here), for much of the stream viewed riparian area in 'reference condition', about 150' of stream disturbed in beginning of reach for pipeline swath with no regrowth of woody vegetation, GIS overestimates road length affecting stream, 1 road crossing - bridge adjacent to upper reach's stream ford, Hamilton Gulch enters in this reach and probably contributes sediment from the RR berm (photos and GPS point), placer tailings visible in field for parts of reach - many prospects continue to be visible on topos in uplands
MT41I006_220	2004 C Ortho	SG_R6	riparian surrounded by low density rural residential	Wetland and Evergreen Forest at base of Grasslands	dense riparian vegetation continues, valley bottom is naturally constricted, some minor grazing impacts and road sediment delivery observed in field, 4 road crossings (mostly driveways), small pond on stream for water diversion at 1st road crossing
MT41I006_220	2004 C Ortho	SG_R7	BLM rec/roaded primary entryway to low density private subdivision	Wetland with some Evergreen Forest at base of Grasslands	most of reach is on BLM property, Skelly Gulch Road is a definite sediment source here exacerbated by beaver dams causing stream to pond and flood road, about 1/5 of reach is within a few feet of road with road berm as separator between stream and road in some areas, channel measures difficult to apply in beaver complex, culvert at Austin Rd is plugged with debris and sediment -water barely trickles through with aide of an overflow culvert
MT41I006_160	2004 C Ortho	SVM_R 1	wetland/occasional grazing allotment adjacent to RR	Wetland at base of Grasslands	reach begins at confluence of Greenhorn Ck. and Skelly Gulch, sediment appears to be problematic even at headwaters, suspect stream is still recovering from alterations for RR and historic placer mining, likely a beaver-wetland complex before alterations -remnant dams and hummocky terrain observed in field with fines as major bank component, stream is incised for most of length, minor encroachment from RR, disturbance visible for small portion of reach from placer mining on RB, sediment delivery from roads documented with GPS in field from ephemeral gully -appears to have moved a lot of load during runoff events, 1 RR crossing
MT41I006_160	2004 C Ortho	SVM_R 2	wetland/occasional grazing allotment adjacent to RR	Wetland at base of Grasslands/Shrubl and/ Evergreen Forest	reach has encroachment from RR (more than captured by GIS as stream course is different than NHD), reach ends at RR crossing

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_160	2004 C Ortho	SVM_R3	some wetland adjacent to RR and rural homesite(grazing/haying)	Wetland at base of Grasslands/ Evergreen Forest	reach has some encroachment from RR, removal of woody vegetation on LB for haying/grazing for about 2/3 of reach length - bank erosion likely a problem ~10% of reach, end of reach is likely a beaver complex with split channels and dense willows (sinuosity and BF don't really apply), Park Creek enters near end of reach and likely delivers sediment during runoff events (ephemeral/intermittent stream) - gully visible in field, 1 irrigation diversion
MT41I006_160	2004 C Ortho	SVM_R4	RR and rural homesites (grazing/haying)	narrow band of Wetland surrounded by Grasslands	reach is mostly single thread sinuous channel with agricultural activities in floodplain (narrow band of woody vegetation), has some encroachment from RR, bank erosion likely a problem ~40% of reach, at least 4 irrigation diversions, 3 feedlots somewhat close to stream, 1 main road crossing
MT41I006_160	2004 C Ortho	SVM_R5	grazing and haying	narrow band of Wetland surrounded by Grasslands	reach is similar to upstream segment except not encroached by railroad, observed portion in field with F. Gruber where channel incision and bank erosion is major source of sediment with ~50% of reach with eroding banks, beaver dam remnants observed, reach begins at place of 2 irrigation diversions
MT41I006_160	2004 C Ortho	SVM_R6	grazing and haying	narrow band of Wetland surrounded by Grasslands and Pasture/Hay	reach begins at irrigation diversion where headgate/dike checks channel incision upstream, thus this reach is severely incised and plagued by steep eroding banks, bank erosion is major source of sediment with ~85% of reach with eroding banks, viewed in field with F. Gruber, beaver dam remnants observed, channel is trying to recover, defunct Ft. Harrison Sewage lagoons near end of reach to RB with animal confinement lots adjacent to lagoons and stream, ~17% of reach has been channelized (possibly for placer mining?), feedlot close to stream at end of reach, 2 road crossings, at least 2 diversions
MT41I006_160	2004 C Ortho	SVM_R7	grazing and haying	Pasture/Hay	short reach almost devoid of riparian vegetation, ends at entry of spring creek which may contribute nutrients from golf course (also receives irrigation water). High Priority AbMine -Franklin and SamGaty in Scratch Gravel Hills above stream may drain to this reach, majority of reach has been channelized (66%) for irrigation/haying purposes, multiple diversions, 2 road crossings, ~75% of reach with eroding banks
MT41I006_160	2004 C Ortho	SVM_R8	grazing and haying with low density residential on outskirts	narrow band of Wetland surrounded by Pasture/Hay	short reach to mouth at Tenmile Creek, some rebound in sinuosity and woody vegetation present, channelization still evident (~50%), observed in field in 2003 with beaver dams, 1 RR crossing, ~65% of reach with eroding banks

Table 5-4. Aerial Sediment Source Assessment: 303(d) Channel Observations

303(d) Segment	Photo Year & Source	Reach ID	Land Use	MRLC Classification	Notes
MT41I006_210	1995 - BW Ortho	JF_R1	private ski area	Evergreen Forest and Grasslands	stream headwaters in mine shaft (HP AbMine: Bald Mountain) on Mt. Belmont, steep slopes and small channel, extensive road network and ski runs dominate riparian area and affect channel form, cistern captures flow at base of ski hill for snow making, stream flows under parking lot in culvert for ~284 feet, excessive ski area runoff observed during spring snow-melt causing sediment loading to stream, improperly sized culverts viewed in 2003 in at least 2 places, at least 3 road crossings, reach is mostly channelized (90%)
MT41I006_210	1995 - BW Ortho	JF_R2	private -seasonal grazing	Evergreen and Deciduous Forest surrounded by Grasslands	overstory riparian provides good canopy, some grazing impacts observed in field during 2003 causing bank erosion and loss of understory woody species in heavily browsed areas, old road that is rarely used affecting stream from past channelization (35%), 1 road crossing
MT41I006_210	1995 - BW Ortho	JF_R3	fringe of Marysville townsite	Grassland	short reach flows on edge of Marysville town, riparian area mostly sedges and grasses, 2 road crossings
MT41I006_210	1995 - BW Ortho	JF_R4	private forest	Evergreen and Deciduous Forest surrounded by Grassland and Shrubland	stream enters forest canopy again, few sources visible save for main road crossing before entering Silver Creek, topos and GIS show prospects/mine sites in uplands of reach

Table 5-5. Historical Aerial Sediment Source Assessment of Upper Prickly Pear Creek: Channel Form

303(d) Segment	PhotoYear & Source	Reach_ID	Reach Length	Elevation Δ	Normalized Reach Length	Valley Length	Normalized Valley Length Factor	Valley Slope	Normalized Valley Slope
MT41I006_060	1956 - BW HC	60_R5	2090	30	1712.5	1932	-0.18	0.016	0.019
MT41I006_060	1956 - BW HC	60_R6	4720	65	5066.5	4182	0.07	0.016	0.014
MT41I006_050	1956 - BW HC	50_R1	3854	42	4058.6	3636	0.05	0.012	0.011
MT41I006_050	1956 - BW HC	50_R2	18200	183	20397.6	15818	0.12	0.012	0.010
MT41I006_050	1956 - BW HC	50_R3	4942	45	5630.6	4708	0.14	0.010	0.008
MT41I006_050	1956 - BW HC	50_R4	4380	40	4383.7	3570	0.00	0.011	0.011
MT41I006_050	1956 - BW HC	50_R5	2196	17	3067.9	2146	0.40	0.008	0.006
MT41I006_050	1956 - BW HC	50_R6	4268	23	3988.9	3762	-0.07	0.006	0.007
MT41I006_040	1956 - BW HC	40_R1	8448	65	9368.5	7526	0.11	0.009	0.008
MT41I006_040	1956 - BW HC	40_R2	11624	55	12859.0	10278	0.11	0.005	0.005
MT41I006_040	1956 - BW HC	40_R3	8870	40	9877.0	7258	0.11	0.006	0.005

Table 5-6. Historical Aerial Sediment Source Assessment of Upper Prickly Pear Creek: Channel Features and Alterations

303(d) Segment	PhotoYear & Source	Reach_ID	Sinuosity	Normalized Sinuosity	Channel Slope	Normalized Channel Slope	Bankfull Width	All Left Bank Encroachment	All Right Bank Encroachment
MT41I006_060	1956 - BW HC	60_R5	1.1	1.1	0.014	0.018	15.2		331
MT41I006_060	1956 - BW HC	60_R6	1.1	1.1	0.014	0.013	17.5	3510	3813
MT41I006_050	1956 - BW HC	50_R1	1.1	1.1	0.011	0.010	12.0	1799	4059
MT41I006_050	1956 - BW HC	50_R2	1.2	1.2	0.010	0.009	17.9	15966	4317
MT41I006_050	1956 - BW HC	50_R3	1.0	1.0	0.009	0.008	12.8	3120	4523
MT41I006_050	1956 - BW HC	50_R4	1.2	1.2	0.009	0.009	17.8	162	1681
MT41I006_050	1956 - BW HC	50_R5	1.0	1.0	0.008	0.006	15.2	1017	2258
MT41I006_050	1956 - BW HC	50_R6	1.1	1.1	0.005	0.006	20.4	3989	3989
MT41I006_040	1956 - BW HC	40_R1	1.1	1.1	0.008	0.007	21.1	7401	6822
MT41I006_040	1956 - BW HC	40_R2	1.1	1.1	0.005	0.004	26.4	3640	4396
MT41I006_040	1956 - BW HC	40_R3	1.2	1.2	0.005	0.004	24.7		

Table 5-7. Historical Aerial Sediment Source Assessment of Upper Prickly Pear Creek: Channel Observations

303(d) Segment	PhotoYear & Source	Reach_ID	LU	Notes
MT41I006_060	1956 - BW HC	60_R5	cultivated field, possibly grazing at end of reach	irrigation diversion at beginning of reach, channel stays on RB side of valley instead of going to LB side today at I15 culverts, thin strip of riparian vegetation, 1 secondary road crossing
MT41I006_060	1956 - BW HC	60_R6	dredge/placer mining	extensive tailings piles fill valley bottom where interstate and frontage road are today, large dredge pond on RB, just downstream of confluence with Beavertown Creek, channel leading away from d. pond as well as multiple channels on LB, probably seeping through tailings piles, most of encroachment from tailings piles, riparian area around LB channels, 2 road crossings (1 placer mining road) - Winston Brothers Placer (GIS)
MT41I006_050	1956 - BW HC	50_R1	dredge/placer mining	continuation of tailings piles, stream has been straightened, no evidence of woody vegetation, looks like flow has been lost possibly at pond, encroachment mainly from tailings piles, 1 road crossing
MT41I006_050	1956 - BW HC	50_R2	dredge/placer mining	continuation of tailings piles, stream crosses tailings piles to RB side of valley where large berm is today, stream is eroding into terrace for approximately 610', encroachment mainly from tailings piles, gravel bar deposits and braiding evident, slope failure or headcutting on steep terrace where Primrose Lane is currently, 2 irrigation diversions visible in reach, *end of reach is 'free flowing' - very sinuous (1.6) woody vegetation, 4 road crossings (1 Hwy)
MT41I006_050	1956 - BW HC	50_R3	transportation corridor	stream is confined between railway bed and highway, some sinuosity in beginning of reach, 1 road crossing at end of reach
MT41I006_050	1956 - BW HC	50_R4	RB transportation corridor, LB rural housing/hay fields	stream is relatively unconfined on LB, but confined in sections on RB by roadway, it appears straightened compared to sinuous section of creek at the end of 50_R2, 1 road crossing (secondary)
MT41I006_050	1956 - BW HC	50_R5	mostly transportation corridor, some hay fields	stream is fairly straight, more confined between road and RR second half of reach, houses right on stream banks (RB) near end of reach (not there today), 1 road crossing 1 RR crossing
MT41I006_050	1956 - BW HC	50_R6	dredge/placer mining	placer diggings appear again, stream is split into two threads near beginning of reach, placer mounds are much smaller piles than upstream ones with piles oriented perpendicular to stream (horizontal piles upstream), piles must be fairly old with deciduous trees growing in them (most likely cottonwoods, similar to upstream mounds, but more trees present), 1 road crossing
MT41I006_040	1956 - BW HC	40_R1	dredge/placer mining transportation corridor	placer diggings continue, but width is not as wide as upstream section, tailings and railway confining stream, vegetation is becoming established along stream corridor, stream splits in 2 after road crossing, detached point bars and gravel bars visible, 2 road crossings (1 RR)
MT41I006_040	1956 - BW HC	40_R2	riparian between transportation corridor, hayfield in beginning of reach	section begins fairly sinuous but then becomes constricted between railway and highway, small section of placer diggings, fairly dense riparian corridor, stream is noticeably wider and downcut in sections, detached point bars visible in areas, 5 road crossings (2 RR, 1 hwy)

Table 5-7. Historical Aerial Sediment Source Assessment of Upper Prickly Pear Creek: Channel Observations

303(d) Segment	PhotoYear & Source	Reach_ID	LU	Notes
MT41I006_040	1956 - BW HC	40_R3	wetland riparian area at base of extractive lu	beginning of reach influenced by transportation corridor, dense riparian vegetation, stream appears to be straightened probably from placer mining - but riparian has recovered, diggings in hillslopes on RB side with some placer mounds visible, timber harvest evident on LB near end of reach, 4 road crossings (4 RR)

5.2 Sediment from Streambank Instability

As discussed in Section 1.2, stream bank erosion was determined to be a potentially significant source of sediment throughout the Lake Helena TPA. Average BEHI ratings for all sediment listed segments varied between "moderate" and "high" for all the listed segments, however intra-segment reach BEHI ratings varied between "low" and "very high" (Table 5-8). Intra-segment variability was a product of heterogeneous land ownership and land use. BEHI rating and reach location were well correlated. Segments with BEHI ratings of "high" were largely confined to higher order stream segments lower in the watershed. Higher ordered segments tend to have finer substrate, and a greater intensity of land use; both, of which result in increased streambank instability.

Sediment load from streambank erosion for the Lake Helena TPA was estimated to be 6162.1 metric tons/year. Of this total, 4815 tons/year were generated within the Prickly Pear watershed, and the remaining 1347 tons/year were generated within the Tenmile/Sevenmile watershed.

Estimated Streambank erosion sediment loads were divided between natural and anthropogenic causes based on field and aerial assessment. Of the total sediment load (6162.1 tons), 4725 tons, or approximately 77% was related to anthropogenic activities, the remaining 1438 tons, or approximately 23% was related to naturally occurring streambank erosion. The results of this analysis on a watershed basis are summarized below in Table 5-8.

Table 5-8. Sediment Loads from Eroding Streambanks by Source

Reach ID	Reach Anthropogenic Related Eroding Banks (%)	Anthropogenic Sediment Load (mt/yr)	Natural Sediment Load (mt/yr)	Total Existing Sediment Load (mt/yr)	Reference Sediment Load (mt/yr)
PP20	85%	516.6	91.2	607.8	49.3
PP30	85%	20.5	3.6	24.1	2.1
PP50	100%	142.4	0.0	142.4	4.0
PP60	55%	1134.7	928.4	2063.1	78.2
Corbin	90%	24.9	2.8	27.7	2.0
Spring	95%	76.8	4.0	80.8	0.7
Clancy	85%	1193.1	210.5	1403.6	221.4
Warm Sprs	60%	35.1	23.4	58.5	12.7
Lump	80%	325.4	81.3	406.7	81.3
Mid-Tenmile	95%	296.8	15.6	312.4	57.3
Lower Tenmile	95%	281.7	14.8	296.5	27.0
Skelly	45%	21.6	26.4	47.9	22.0
Sevenmile	95%	652.2	34.3	686.5	17.5
Jennies Fork	70%	2.7	1.2	3.9	1.5

Reference condition eroding streambank quantities were calculated based on data collected from reference stream segments, described in Section 1.2.2 above. The load reduction target value for anthropogenic streambank erosion is the segment reference level sediment load (Table 5-9).

Table 5-9. Collected Lake Helena BEHI data.

Sample Location Reach ID	Length of Eroding Bank (% of Reach Length)	Total Reach Eroding Bank Length (feet)	Bank Length (yds)	Bank Height (ft)	Bankfull Height (ft)	Root Depth (ft)	Root Density (%)	Bank Angle (degree)	Surface Protect (%)	BEHI Score	Average BEHI Rating	Average Sediment Load (mt/year) (from survey)
PP20	60.0%	6067.9	86	7.0	2.0	0.3	5	85	20	Very High		
PP20	40.0%	5368.4	40	6.0	2.5	2.0	12	60	30	High		
PP20	5.0%	550.2	18	4.0	2.5	1.0	18	40	1	High		
PP20	35.0%	12088.2	48	1.9	1.2	0.7	90	145	9	Very High		
PP20	35.0%	12088.2	48	1.4	0.8	1.2	90	79	9	Moderate	**32.19**	
PP20	35.0%	12088.2	48	1.5	0.9	1.5	90	69	9	Moderate	**High**	795.55
PP30	12.0%	1645.3	25	5.0	2.0	1.5	40	85	30	High		
PP30	12.0%	2984.3	25	2.1	0.3	0.7	40	40	23	High		
PP30	12.0%	2984.3	25	2.3	0.2	0.5	40	32	68	Moderate		
PP30	12.0%	2984.3	25	1.9	0.5	1.9	68	84	24	Moderate		
PP30	12.0%	2984.3	25	1.8	0.7	0.4	42	75	8	High		
PP30	12.0%	2984.3	25	1.5	1.0	0.7	24	86	8	High	**31.30**	
PP30	12.0%	2984.3	25	1.1	1.0	0.2	24	65	8	High	**High**	196.72
PP50	15.0%	2572.6	25	5.0	1.5	1.4	25	90	1	Very High		
PP50	10.0%	528.3	6.7	3.5	1.5	1.0	12	80	25	High		
PP50	5.0%	193.1	14	5.5	1.7	1.6	10	60	80	High		
PP50	10.0%	3713.0	15	1.2	0.7	0.3	63	72	23	Moderate		
PP50	10.0%	3713.0	15	1.0	0.6	0.4	90	90	42	Moderate	**29.78**	
PP50	10.0%	3713.0	15	1.2	0.8	0.6	90	75	32	Moderate	**Moderate**	149.43
PP60	22.0%	1280.4	5	9.0	1.8	2.1	30	80	1	High	**37.87** **High**	469.19
Corbin	22.0%	3276.9	30	0.9	0.6	0.2	70	55	24	Moderate		
Corbin	22.0%	3276.9	30	0.8	0.6	0.1	70	14	24	Moderate	**26.91**	
Corbin	22.0%	3276.9	30	1.2	0.1	0.1	70	32	12	High	**Moderate**	93.93
Spring	22.0%	5784.6	30	1.0	0.8	0.2	95	90	12	Moderate		
Spring	22.0%	5784.6	30	0.3	0.2	0.1	90	9	24	Moderate	**23.91**	
Spring	22.0%	5784.6	30	0.9	0.5	0.4	90	48	12	Moderate	**Moderate**	87.25
Clancy	1.0%	85.9	2.7	2.5	0.8	0.8	15	60	25	High		
Clancy	70.0%	6984.6	6	5.0	1.5	2.0	45	65	70	Moderate		
Clancy	50.0%	3318.1	33.3	3.5	2.0	1.5	40	80	40	Moderate		
Clancy	40.0%	27072.7	14	1.2	0.5	0.8	90	4	21	Moderate		
Clancy	40.0%	27072.7	14	1.0	0.6	0.2	62	29	21	Moderate		
Clancy	40.0%	27072.7	14	1.2	0.7	1.0	90	24	42	Low		
Clancy	40.0%	27072.7	14	0.6	0.4	0.1	42	25	42	Moderate		

Table 5-9. Collected Lake Helena BEHI data.

Sample Location Reach ID	Length of Eroding Bank (% of Reach Length)	Total Reach Eroding Bank Length (feet)	Bank Length (yds)	Bank Height (ft)	Bankfull Height (ft)	Root Depth (ft)	Root Density (%)	Bank Angle (degree)	Surface Protect (%)	BEHI Score	Average BEHI Rating	Average Sediment Load (mt/year) (from survey)
Clancy	40.0%	27072.7	14	0.8	0.6	0.3	68	68	42	Moderate	**25.31**	
Clancy	40.0%	27072.7	14	1.1	0.5	0.6	90	120	90	Moderate	**Moderate**	412.22
Warm Sprs	8.0%	104.1	16	2.8	1.3	1.5	12	75	15	High		
Warm Sprs	8.0%	1370.5	16	4.6	1.0	0.2	22	36	12	High		
Warm Sprs	8.0%	1370.5	16	1.5	0.7	0.6	42	120	43	High	**32.71**	
Warm Sprs	8.0%	1370.5	16	1.3	0.8	0.4	42	57	42	Moderate	**High**	96.68
Lump	22.0%	17050.0	30	3.2	2.6	1.0	90	100	95	Moderate		
Lump	22.0%	17050.0	30	1.6	1.2	0.7	95	110	95	Moderate	**22.77**	
Lump	22.0%	17050.0	30	1.8	1.2	0.6	95	120	95	Moderate	**Moderate**	778.57
Mid-Tenmile	15.0%	1109.7	20	7.5	2.5	2.7	40	45	75	Moderate		
Mid-Tenmile	17.0%	6682.9	46.6	1.4	2.5	1.3	42	51	38	Low		
Mid-Tenmile	17.0%	6682.9	46.6	3.6	0.5	0.6	42	14	38	Moderate	**21.67**	
Mid-Tenmile	17.0%	6682.9	46.6	1.5	1.2	1.0	68	60	38	Low	**Moderate**	173.01
Low Tenmile	20.0%	2027.5	23	5.5	4.0	2.0	10	85	40	Moderate		
Low Tenmile	0.5%	64.7	55	5.5	2.2	1.0	8	90	10	Very High		
Low Tenmile	2.0%	200.7	60	3.5	1.0	1.7	30	68	1	High		
Low Tenmile	45.0%	2843.6	75	3.0	2.5	1.5	12	90	8	High		
Low Tenmile	17.0%	6682.9	53.25	1.7	0.7	0.6	90	50	38	Moderate		
Low Tenmile	17.0%	6682.9	53.25	1.8	1.2	0.7	90	120	22	High		
Low Tenmile	17.0%	6682.9	53.25	0.9	0.5	0.5	90	110	42	Moderate		
Low Tenmile	17.0%	14809.8	53.25	1.2	0.6	0.7	22	125	12	Very High		
Low Tenmile	17.0%	14809.8	53.25	3.8	0.6	2.3	12	77	9	High	**33.24**	
Low Tenmile	17.0%	14809.8	53.25	3.5	0.8	2.2	22	75	12	High	**High**	615.82
Skelly	22.0%	9065.0	30	1.4	0.5	1.4	68	135	90	High		
Skelly	22.0%	9065.0	30	0.5	0.2	0.5	68	20	90	Low	**22.00**	
Skelly	22.0%	9065.0	30	0.5	0.2	0.5	68	24	90	Low	**Moderate**	169.87
Sevenmile	22.0%	9811.7	30	2.7	1.3	1.9	68	140	7	Very High		
Sevenmile	22.0%	9811.7	30	4.0	1.2	0.9	68	56	7	High	**37.34**	
Sevenmile	22.0%	9811.7	30	1.7	0.9	0.8	68	120	7	High	**High**	1036.07
Jennies Fork	22.0%	1578.4	30	0.6	0.5	0.1	68	52	68	Low		
Jennies Fork	22.0%	1578.4	30	0.6	0.4	0.3	68	75	42	Moderate	**22.32**	
Jennies Fork	22.0%	1578.4	30	1.0	0.4	0.8	68	76	68	Moderate	**Moderate**	17.78

5.3 Abandoned Mine Related Sediment

GWLF does not have the capability to model sediment load associated with abandoned mines. Consequently abandoned mines were modeled with an alternative methodology, developed by CDM for USEPA for use in the Upper Tenmile Creek Superfund area. Tables below describe the sediment loads associated with each mine site determined to be a sediment source (Table 5-10), and on a watershed basis (Table 5-11). Five of the mines (Gregory, Alta, Bertha, Nellie Grant, and Corbin Flats) have been reclaimed in recent years, and correspondingly the associated sediment yield has decreased (Table 5-10, and 5-11). Reduction of mine specific sediment production was calculated by measuring the area of un-vegetated polygons (with laser rangefinder and/or measuring wheel), and applying an appropriate sediment delivery ratio to these areas, within the total mine site area. This un-vegetated area was subtracted from the total mine site area in order to calculate the total vegetated area, which are no longer generating detectable quantities of sediment. The difference in the pre- and post-reclamation vegetated area and sediment delivery ratio resulted in the post-reclamation sediment load reduction.

The total pre-reclamation sediment load from abandoned mines was 1097.8 tons/year, or 0.03% of the total Lake Helena sediment load; total post reclamation sediment load was 455.5 tons/yr, or 0.01% of total Lake Helena sediment load. Watershed wide, reclamation activities reduced abandoned mine related sediment yield by 642.3 ton/year, or 59% of pre-reclamation total sediment load. Based on data collected from the five reclaimed abandoned mine sites, the average decrease in percent sediment reduction from pre- to post-reclamation per mine was 79%. Consequently, the abandoned mines sediment reduction target was set at 79% of existing sediment load.

Table 5-10. Sediment Loads by Abandoned Mine Site

Mine	Watershed	Total Sediment Producing Area (ft2)	Pre-reclamation Sediment Load (t/yr)	Post-reclamation Sediment Load (t/yr)
CRAWLEY CAMP	Clancy Creek	No data		
GREGORY	Clancy Creek	77235	32.8	0.0
ALTA	Corbin Creek	39000	16.1	16.1
BERTHA	Corbin Creek	12510	4.4	0.06
BLACK JACK MINE	Corbin Creek	11768.75	4.6	N/A
NELLIE GRANT	Lump Gulch	5040	1.0	0.01
FROHNER MINE AND MILL	Lump Gulch	87120	44.1	N/A
YAMA GROUP MINE	Lump Gulch	33750	6.2	N/A
MIDDLE FORK WARM SPRINGS	Middle Fk. Warm Springs	27300	8.8	N/A
SOLAR SILVER	Middle Fk. Warm Springs	12000	4.9	N/A
NEWBURGH MINE / FLEMING MINE	Middle Fk. Warm Springs	205920.7	81.1	N/A
WARM SPRINGS TAILINGS ADIT	Middle Fk. Warm Springs	369453.2	98.7	N/A
WHITE PINE MINE	Middle Fk. Warm Springs	70638.6	31.9	N/A
ARMSTRONG MINE	Middle Tenmile Creek	46475	13.8	N/A
BEATRICE	Middle Tenmile Creek	7695	2.3	N/A
UPPER VALLEY FORGE	Middle Tenmile Creek	7590	2.2	N/A
COPPER GULCH	Prickly Pear above Spring Creek	19602	3.9	N/A
BLUEBIRD	Spring Creek	87914.98	47.0	N/A
CORBIN FLATS	Spring Creek	1742400	587.9	0.0
WASHINGTON	Spring Creek	61440	31.5	N/A
SALVAI / MT WASHINGTON MINE	Spring Creek	32065.3	10.9	N/A
MONITOR CREEK TAILINGS	Upper Tenmile Creek	10500	5.3	N/A
NATIONAL EXTENSION	Upper Tenmile Creek	12000	6.1	N/A
PETER	Upper Tenmile Creek	1150	0.6	N/A
RED MOUNTAIN	Upper Tenmile Creek	15675	6.2	N/A
RED WATER	Upper Tenmile Creek	4500	2.3	N/A
VALLEY FORGE/SUSIE	Upper Tenmile Creek	26700	10.4	N/A
WOODROW WILSON	Upper Tenmile Creek	600	0.3	N/A
BADGER	Warm Springs Creek	43877.5	19.7	N/A

Table 5-11. Sediment Loads from Abandoned Mine Sites by Sub-Watershed

Sub-watershed	Pre-reclamation Delivered Sediment Load (t/yr)	Post-reclamation Delivered Sediment Load (t/yr)	Reduction in Sediment Load from reclamation activities (%)
Clancy Creek	32.8	0.0	100%
Corbin Creek	25.1	4.7	81.3%
Spring Creek	677.4	89.5	86.8%
Lump Gulch	51.3	50.3	1.9%
Middle Fork Warm Springs	225.4	N/A	0.0%
Warm Springs Creek	19.7	N/A	0.0%
Prickly Pear above Spring Creek	3.9	N/A	0.0%
Silver Creek	12.5	N/A	0.0%
Middle Tenmile Creek	18.3	N/A	0.0%
Upper Tenmile Creek	31.2	N/A	0.0%
Total	1097.8	N/A	0.0%

5.4 Potential Sediment Loading Risk from Culvert Failure

Culvert survey data within the Lake Helena TPA was unavailable. Sediment loading related to potential culvert failure was based on a culvert hazard analysis conducted by Helena National Forest personnel within the Poorman Creek watershed. The average culvert fill volume associated with culvert failure was 842.6 ft.^{3}/per culvert (calculated from reported culvert fill dimensions). Based on a dry material density of 125 lbm/ft^3, the resultant average sediment load would be 52.7 tons per culvert failure.

In order to generate potential sediment loading from culvert failure within the Lake Helena TPA, all paved roads were assumed to utilize bridges for stream crossings, and all gravel/native surfaced roads were assumed to utilize culverts for road-stream crossings, and thus the focus of culvert failure. The results from this analysis are displayed on a listed segment basis in Table 2.12, below. Total potential sediment load from within the Lake Helena TPA was 18,642 tons. Watersheds with the greatest potential for sediment contributions were those with large numbers of graveled road stream crossings, which typically were located on county and Forest Service roads in more rural parts of the watersheds.

Available data suggest that approximately 45% of the culverts within the Lake Helena watershed are at a high risk of failure due to inappropriate culvert sizing. Sediment from culvert failure was not factored into the TMDL load allocation because it is a theoretical load. However, with the proper meteorological event this load could become a reality. It is presented in this appendix for reference purposes, and the hope that road related BMP upgrades will include culvert replacement and enlargement.

Table 5-12. Estimates of Sediment Loads from Culvert Failure

Watershed	Watershed Size (mi^2)	Miles of Roads	Road Density (mi/mi^2)	Road Erosion Sediment Load (metric tons/year)	Number of Stream Crossings[1]	Potential Culvert Failure Sediment Load (metric tons)
Prickly Pear MT411006_020	6.6	29.3	4.5	3.3	14	47.8
Prickly Pear MT411006_030	19.4	150.3	7.7	84.8	108	47.8
Prickly Pear MT411006_040	73.7	226.6	3.1	776.4	291	1672.0
Prickly Pear MT411006_050	25.4	63.8	2.5	237.9	81	1242.1
Prickly Pear MT411006_060	26.7	50.0	1.9	432.3	61	1003.2
Corbin Creek MT411006_090	2.7	8.1	3.0	87.5	12	286.6
Spring Creek MT411006_080	18.2	55.9	3.1	453.6	69	2102.0
Clancy Creek MT411006_120	33.0	53.5	1.6	418.9	79	571.8
North Fork Warm Springs MT411006_180	2.1	5.7	2.7	82.7	5	47.8
Middle Fork Warm Springs MT411006_100	3.4	2.5	0.7	48.7	5	238.9
Warm Springs MT411006_110	15.1	21.5	1.4	214.3	52	1003.2
Lump Gulch MT411006_130	43.4	106.4	2.5	852.2	124	2197.5
Middle Tenmile MT411006_142	38.6	58.2	1.5	438.8	78	1767.6
Lower Tenmile MT411006_143	76.2	253.0	3.3	327.7	244	668.8
Skelly Gulch MT411006_220	38.9	21.4	1.8	248.4	29	525.5
Sevenmile Creek MT411006_160	38.9	79.1	2.0	318.8	133	1194.3
Jennies Fork MT4110066_210	1.0	7.1	3.6	244.6	11	477.7

[1] Based on GIS road and stream layers. Some crossings that appear on GIS layers may not actually exist on the ground.

5.5 WEPP:Road, Additional Roads Assessment

Results from the WEPP:Road road sediment modeling analysis were highly variable. This result was not unexpected due to the variety of road configurations surveyed during the data collection phase. The majority of the modeled road sediment was related to a minority of unpaved road segments. This was confirmed during source assessment data collection, as a few isolated road segments produced the majority of the sediment. The combination of field source assessment and site specific modeling will assist with restoration priority development, as well as load reduction related to restoration/BMP implementation.

Total sediment load modeled by WEPP:Road was 225.5 metric tons, the majority of this sediment is related to three watersheds, upper Tenmile (70.4 mt), Sevenmile (54.9 mt), and Prickly Pear 40 (25.5 mt). Direct model comparisons between GWLF road output and WEPP:Road would be inappropriate due to differences in model scale and function. The WEPP generated data will only be used to set restoration priorities.

6.0 CONCLUSIONS

The results of the supplemental sediment source assessment modules will serve as a tool for setting restoration priorities within the Lake Helena watershed and have, in some cases, provided a means for validating results produced by GWLF. Efforts were made to reduce the uncertainty associated with the generated sediment loads via field verification, consultation with watershed experts, and implementation of established models and methodologies. However, given the size of the watershed and extent of sediment impairments, some level of uncertainty is unavoidable. It is anticipated that additional source assessment will likely be necessary prior to implementing future restoration activities. The GPS locations and photographs of field survey sites will be on file with the Montana Department of Environmental Quality, and represent areas within the watershed with documented erosion problems.

7.0 REFERENCES

Montana DEQ, Abandoned Mines Section. 2005. Access to the abandoned mine files at the Mine Waste Cleanup Bureau. Helena, MT.

Montana Natural Resource Information System. 2003. Montana State Library GIS Data List. NRIS website at http://nris.state.mt.us/gis/datalist.html. 2003 - 2005.

Metesh, J.J., J. Lonn, R.K. Marvin, P. Hargrave, and J.P. Madison. 1998. Abandoned-Inactive Mines Program, Helena National Forest, Volume I: Upper Missouri River Drainage. Montana Bureau of Mines and Geology Open File Report 352. Butte, MT.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.
Stuart, Bo. 2003 to 2005. Personal communication with Land & Water Consulting, Inc. multiple times during 2003, 2004, and 2005 concerning the Helena National Forest.

Toy, T.J., G.R. Foster, and J.R. Galetovic. 1998. Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands. Office of Technology Transfer, Western Regional Coordinating Center, Office of Surface Mining. Available at http://www.ott.wrcc.osmre.gov/library/hbmanual/rusle/frontmatter.pdf

USEPA. 2004. Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area: Volume I – Watershed Characterization and Water Quality Status Review. Helena, MT.

USDA. 2005. Water Erosion Prediction Project, WEPP. USFS Soil & Water Engineering, Moscow, ID. Available at http://forest.moscowfsl.wsu.edu/fswepp/

Appendix E

Point Sources

Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report

August 31, 2006

Prepared for the Montana Department of Environmental Quality

Prepared by the U.S. Environmental Protection Agency,
Montana Operations Office
With Technical Support from Tetra Tech, Inc.
and PBS&J, Inc.

Project Manager: Ron Steg

Contents

1.0 POINT SOURCES 1
1.1 MPDES Permits 3
1.1.1 Evergreen Nursing Facility (MT0023566) 3
1.1.2 City of Helena WWTP (MT0022641) 3
1.1.3 City of East Helena WWTP (MT0022560) 5
1.1.4 ASARCO (East Helena Lead Smelter) (MT0030147) 5
1.1.5 Golden Estates Subdivision (MTX000135) 6
1.1.6 Ash Grove Cement Company (MT0000451) 6
1.1.7 Air Liquide (MT0000426) 6
1.1.8 Montana Tunnels Mine (MT0028428) 6
1.2 Stormwater Permits 7
1.2.1 ASARCO (MTR000072) 7
1.2.2 Helena Regional Airport (MTR000271), National Guard (MTR000428), and UPS (MTR000334) . 7
1.2.3 Montana Rail Link (MTR000361) 7
1.2.4 Pacific Steel and Recycling (MTR000430) 7
1.2.5 Ash Grove Cement Company (MTR300113) 8
1.2.6 Air Liquide (MTR000006) 8
1.2.7 Lewis and Clark County Landfill (MTR000363) 8
1.3 Non-Permitted Discharges 8
1.3.1 Eastgate Subdivision (No DEQ Permit) 8
1.3.2 Treasure State Acres Subdivision (No DEQ Permit) 8
1.3.3 Tenmile and Pleasant Valley Subdivisions (No DEQ Permit) 9
1.3.4 Leisure Village Mobile Home Park (No DEQ Permit) 9
1.3.5 Mountain View Academy (No DEQ Permit) 9
1.3.6 Fort Harrison (No DEQ Permit) 9
1.4 City of Helena MS4 Stormwater Permit (MTR040003) 10
2.0 REFERENCES 13

1.0 POINT SOURCES

There are eight permitted point sources and seven permitted stormwater discharges in the Lake Helena watershed (Figure 1). There are also six small facilities that are not required to have Montana Pollutant Discharge Elimination System (MPDES) permits. The following sections summarize each facility's flow, and permitted nutrient and metals data. Furthermore, the receiving waterbody, and any other information that might be relative to the Lake Helena TMDL Planning Area are discussed. Information was obtained from EPA's online Permit Compliance System Database (PCS), from Montana DEQ paper records, from the 1998 Helena Area Wastewater Treatment Facility Plan (Damschen & Associates, Inc.), and from personal communications with Montana DEQ staff.

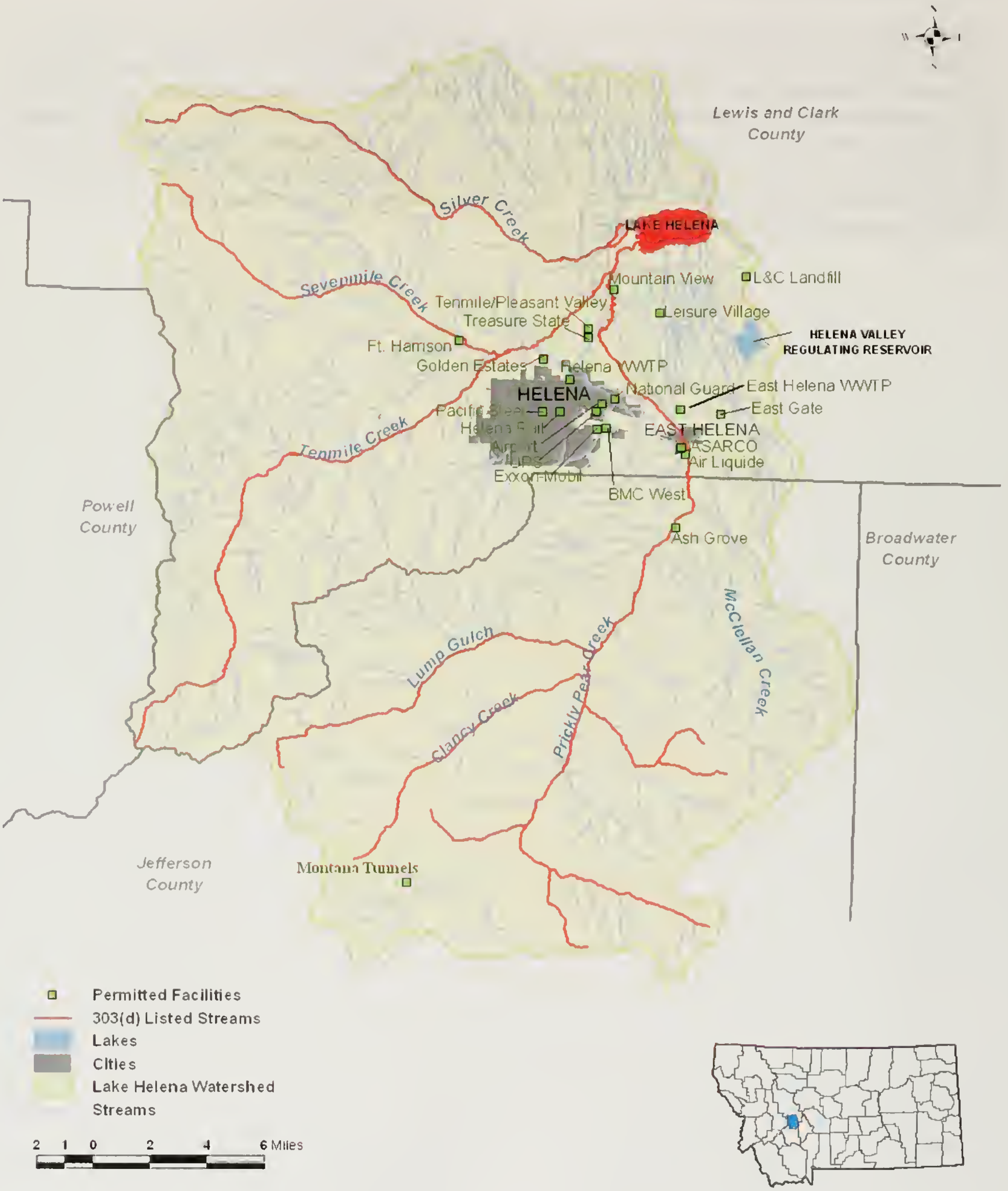


Figure 1. Location of point sources in the Lake Helena watershed.

1.1 MPDES Permits

The following sections summarize the MPDES permitted point sources in the Lake Helena watershed.

1.1.1 Evergreen Nursing Facility (MT0023566)

The Evergreen Nursing Facility is located in Clancy, Montana in the Prickly Pear Creek subwatershed. The facility operates a secondary treatment activated sludge wastewater system with a design flow of 15,000 GPD. Under Montana DEQ Permit #MT0023566 (issued for December 1995 to November 2000), the facility has a permitted discharge of 15,000 GPD, and does not currently have permit limits for any species of nitrogen or phosphorus. Thirty-four occupants along with all support staff for the Evergreen Nursing facility are served by this system. Discharge from the facility enters a small cooling pond (1-5 hour retention time) before finally discharging to Prickly Pear Creek (Jim Llyod, Personal Communications, September 27, 2005). Water from the facility's geothermal heating system is also routed through the retention pond. The average observed flow rate from January 1998 to April 2005 was 6,876 GPD, with an average TN concentration of 11.9 mg/L, an average TP concentration of 2.9 mg/L, and an average NO_2NO_3 concentration of 8.4 mg/L.

1.1.2 City of Helena WWTP (MT0022641)

The City of Helena wastewater treatment facility is located in the northeast section of Helena, Montana in the Prickly Pear Creek subwatershed. Prior to 2001, the facility operated a secondary treatment biotower system. In June of 2001, an advanced secondary treatment wastewater system with nitrification/ denitrification went online. Under Montana DEQ Permit #MT0022641 (issued for December 1996 to October 2001), the facility has a permitted discharge of 6.2 MGD, and permitted ammonia limits that vary per month (see Montana DEQ Circular WQB7). No other nutrient parameters have permit limits. At the time of the permit application, the system served approximately 30,000 people from the City of Helena and surrounding areas, encompassing an area of 15.8 square miles. With 30,000 people, the system is running at half capacity (assuming 100 GPD per person). The City of Helena currently has plans to annex an additional 5.3 square miles in the Tenmile Creek and the Prickly Pear Creek subwatersheds (see Figure 2). Transitional areas of concern (15.9 sq. mi.) have also been identified for possible annexation at a later date.

Discharge from the Helena treatment plant enters an unnamed irrigation ditch that originates near the facility, and eventually flows into Prickly Pear Creek. However, during the irrigation season (April-October), irrigators withdraw water from the ditch, and surface water flows from the plant rarely reach Prickly Pear Creek. Solid waste is either composted, land applied, or stored in a landfill. The average observed flow rate from June 2001 to July 2005 was 3.1 MGD, with an average TN concentration of 7.9 mg/L, an average TP concentration of 4.9 mg/L, and an average NO_2NO_3 concentration of 5.2 mg/L.

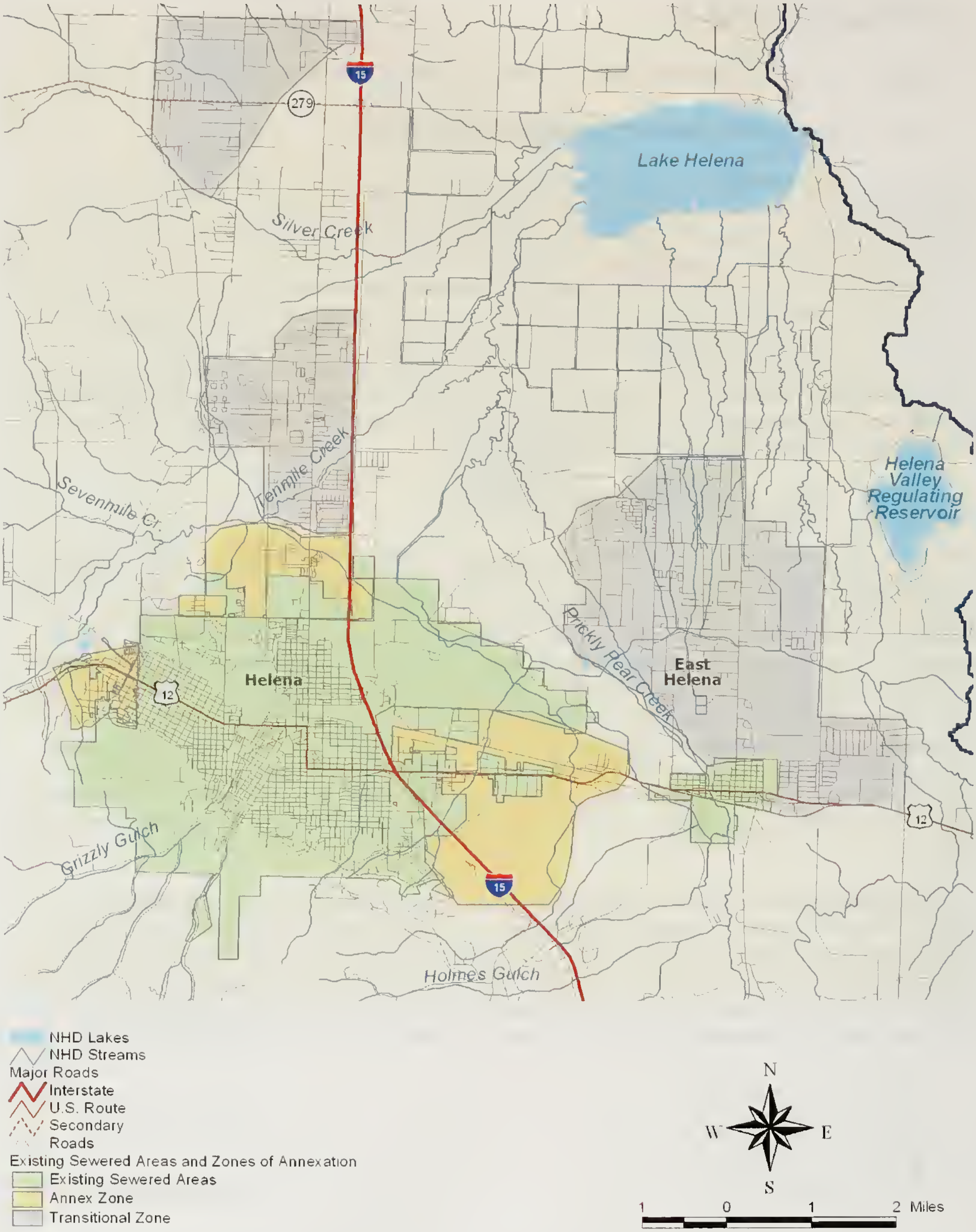


Figure 2. Area served by the city of Helena and East Helena wastewater treatment systems.

1.1.3 City of East Helena WWTP (MT0022560)

The City of East Helena wastewater treatment facility is located approximately 0.5 miles north of the city in the Prickly Pear Creek subwatershed. Prior to 2003, the facility operated three partially mixed ponds with a designed retention time of 30-days. In 2003, the plant was renovated and now operates an advanced secondary treatment activated sludge system with nitrification. Under Montana DEQ Permit #MT0022560 (issued for April 1997 to March 2002), the facility has a permitted discharge of 0.43 MGD, permitted TP load of 20 lbs/day, and a permitted TN load of 80 lbs/day. At the time of the permit application, the system served approximately 1,673 people from East Helena and the surrounding area (excluding the Eastgate Subdivision), encompassing an area of approximately one square mile (see Figure 2). With 1,673 people, the system is running at 39 percent of capacity (assuming 100 GPD per person).

Discharge from the East Helena treatment plant enters an unnamed ditch that discharges into Prickly Pear Creek. The average observed flow rate from January 2003 to July 2005 was 0.20 MGD, with an average TN concentration of 23.2 mg/L, an average TP concentration of 3.6 mg/L, and an average NO_2NO_3 concentration of 14.3 mg/L. Ammonia concentrations were non-detectable for most sampling events (less than 0.1 mg/L). Prior to the plant upgrade, ammonia concentrations were much higher (average of 4.1 mg/L) and NO_2NO_3 concentrations much lower (average of 1.0 mg/L). The current values reflect the facility's new nitrification system, which converts ammonia to nitrate and nitrite.

1.1.4 ASARCO (East Helena Lead Smelter) (MT0030147)

The ASARCO wastewater treatment facility is located in the City of East Helena, Montana in the Prickly Pear Creek subwatershed. Due to the history of plant operations and upgrades, wastewater flows and quality have dramatically changed over the years. This analysis focuses on the operation of the ASARCO facility from April 2001 (when the plant stopped full operations) through the present (September 2005).

Currently, the ASARCO facility operates a three-phase high-density sludge (HDS) wastewater treatment system. Under Montana DEQ Permit #MT0030147 (issued for November 1996 to September 2001), the facility has a permitted discharge of 158,400 GPD, and a load based permit for various metals. Permitted metals loads include arsenic (2.55 lbs/day), cadmium (0.2061 lbs/day), copper (2.354 lbs/day), lead (0.515 lbs/day), and zinc (1.88 lbs/day). No species of nitrogen or phosphorus have permit limits. Since the plant is not currently operational, the wastewater facility currently only treats water from remediation wells and onsite general water use (bathrooms, sinks, etc.). Water from these sources is stored in large tanks, and then is processed by the treatment plant when needed. Therefore, discharge from the facility only occurs several times per month (Jim Llyod, Personal Communications, September 27, 2005).

The ASARCO facility has a 4.6 CFS water right for Prickly Pear Creek dating back to 1862, which it uses to fill two ponds located on the property. Discharge from treatment plant then enters the unnamed downstream (lower) pond, which has approximately a 10-day retention time. The pond is directly connected to Prickly Pear Creek. The average observed flow rate from April 2001 to August 2005 (during months having flow) was 33,535 GPD, with 19 months having no discharge. No TN or NO_2NO_3 data have been collected at the facility. TP concentrations averaged 0.08 mg/L, and total ammonia nitrogen averaged 1.2 mg/L.

1.1.5 Golden Estates Subdivision (MTX000135)

The Golden Estates Subdivision is located approximately 0.3 miles north of the City of Helena in the Prickly Pear Creek subwatershed. The subdivision operates a pressure dosed subsurface drainfield with a design flow of 12,600 GPD. Under Montana DEQ Permit #MTX000135 (issued for September 2002 to September 2007), the facility has a permitted discharge of 12,600 GPD, and has load based permit limits for total nitrogen and total phosphorus (2.42 and 1.11 pounds per day, respectively). At full build out, 42 homes in the Golden Estates Subdivision are served by this facility (approximately 101 people). Discharge from the facility enters the drainfield and groundwater. The average observed flow rate from March 2004 to June 2005 was 6,289 GPD, with an average TN concentration of 28.1 mg/L, and an average TP concentration of 6.8 mg/L. No nitrate-nitrite or ammonia data were available.

1.1.6 Ash Grove Cement Company (MT0000451)

The Ash Grove Cement Company is located Montana City, Montana in the Prickly Pear Creek subwatershed. The facility operates two sedimentation ponds that are used to dispose of process water (Montana DEQ Permit #MT0000451). The permit was issued for March 1996 to October 2000. The facility has no permit limits for flow or nutrients. Water generally infiltrates into the groundwater, and any overflows from the sedimentation basins flow into Prickly Pear Creek. In 91 months of sampling (January 1998 to July 2005), there were no discharge events from the ponds.

1.1.7 Air Liquide (MT0000426)

The Air Liquide Facility is located in East Helena, Montana in the Prickly Pear Creek subwatershed. The facility discharges non-contact cooling water (Montana DEQ Permit # MT0000426) into Prickly Pear Creek. The permit was issued for December 2003 to January 2009. The facility has no permit limits for flow, metals, or nutrients. Water is discharged into a drainage ditch that flows into Prickly Pear Creek. Average discharge from the facility between March 2004 and June 2005 was 20,808 GPD, and the facility is not required to monitor nutrient concentrations in the industrial effluent.

1.1.8 Montana Tunnels Mine (MT0028428)

The Montana Tunnels Mine is an open pit gold mine located approximately 7 miles southwest of Jefferson City, Montana in the Spring Creek, Clancy Creek, and Corbin Creek subwatersheds. The Montana DEQ Permit (MT0028428) covers an area of 2,116 acres, although only 1,146.4 acres are permitted for disturbance (MDEQ, 2002). In 2002, an environmental assessment was approved by Montana DEQ to allow Montana Tunnels, Inc. to expand the mining operation by 17.2 acres. The Montana Tunnels Mine produced 33,743 ounces of gold in 2004, and also had payable production of 970,751 ounces of silver, 10,064,265 pounds of lead and 26,222,805 pounds of zinc (Apollo Gold, 2005).

According to Montana DEQ, mill process water and storm water runoff are contained in a closed loop system that recycles water for the mill operations (Personal Communications, Jim Lloyd, November 22, 2005). The closed system is comprised of a sedimentation basin in the Pen Yan Creek watershed, the mill, the mine, and the tailings impoundment. No surface water discharges have been recorded in the Montana DEQ permit records (1987-2005).

Permit limits for the Montana Tunnels Mine are 0.29 mg/L for arsenic, 0.004 mg/L for cadmium, 0.01 mg/L for copper, 0.05 mg/L for lead, and 0.12 mg/L for zinc. It should be noted that the current arsenic permit limit is 0.28 mg/L greater than revised Montana DEQ human health arsenic standard of 0.01 mg/L.

1.2 Stormwater Permits

The following sections summarize the stormwater permits in the Lake Helena watershed.

1.2.1 ASARCO (MTR000072)

ASARCO has a stormwater permit (MTR000072) that was issued for January 2002 through September 2006. Stormwater from the facility is routed into a sedimentation basin that is designed to accommodate a 50-year storm event. When needed, discharge from the basin flows into the hay fields adjacent to the facility. However, no discharge has been recorded from the basin.

1.2.2 Helena Regional Airport (MTR000271), National Guard (MTR000428), and UPS (MTR000334)

The Helena Regional Airport is located in the northeast section of Helena, Montana in the Prickly Pear Creek subwatershed. The facility has a permit (Montana DEQ Permit #MTR000271) to discharge stormwater into multiple ponds that eventually drain to Prickly Pear Creek, the Helena Irrigation Canal, the City of Helena sewer system, and groundwater. The permit was issued for January 2002 through September 2006. The Helena Airport stormwater drainage system is complex in that it receives water from a large area including portions of East Helena, Interstate 15, and the upper east section of Helena (From Saddle Mountain to the Airport). Furthermore, there are multiple ponds draining to multiple waters, which make tracking and monitoring difficult. Between June 2002 and June 2005, there were no reported discharge events from the detention ponds. Both the Army National Guard (Montana DEQ Permit #MTR000428) and the United Parcel Service (Montana DEQ Permit #MTR000334) facilities are located at or near the Helena Airport, and essentially share the same stormwater runoff system.

1.2.3 Montana Rail Link (MTR000361)

Montana Rail Link is located in central Helena, Montana in the Prickly Pear Creek subwatershed. The facility has a permit (Montana DEQ Permit #MTR000361) to discharge stormwater into the City of Helena storm sewer via several storm drains, ditches, and vaults. The permit was issued for January 2002 through September 2006, and addresses runoff from 34 acres of the Montana Rail Link Facility. Between June 2002 and June 2005, there were five reporting periods (one reporting period equals 6 months) with runoff events, and the average flow was 20,000 GPD. Two reporting events had no flow. No nutrient data were available for the runoff events.

1.2.4 Pacific Steel and Recycling (MTR000430)

Pacific Steel and Recycling has a permit (Montana DEQ Permit #MTR000430) to discharge stormwater into an onsite detention pond designed to contain a 25 year storm event. The pond then discharges into the City of Helena Storm Sewer, which flows to Tenmile Creek. The permit was issued for October 2001 through September 2006, and addresses runoff from the recycling yard. The facility is not required by Montana DEQ to monitor stormwater runoff.

1.2.5 Ash Grove Cement Company (MTR300113)

The Ash Grove Cement Company is located Montana City, Montana in the Prickly Pear Creek subwatershed. The facility operates two sedimentation ponds that are used to dispose of onsite stormwater (Montana DEQ Permit #MTR300113) and process water (see Section 1.1.6). The permit was issued for March 1996 to October 2000. The facility has no permit limits for flow or nutrients. Water generally infiltrates into the groundwater, and any overflows from the sedimentation basins flow into Prickly Pear Creek. In 91 months of sampling (January 1998 to July 2005), there were no discharge events from the ponds.

1.2.6 Air Liquide (MTR000006)

The Air Liquide Facility is located in East Helena, Montana in the Prickly Pear Creek subwatershed. The facility discharges onsite stormwater (Montana DEQ Permit #MTR000006) into Prickly Pear Creek. The permit was issued for December 2003 to January 2009. The facility has no permit limits for flow or nutrients. Water is discharged into a drainage ditch that flows into Prickly Pear Creek, and no monitoring data were available for stormwater runoff.

1.2.7 Lewis and Clark County Landfill (MTR000363)

The Lewis and Clark County Landfill is located approximately two miles southeast of Lake Helena in the subwatershed draining directly to Lake Helena. The facility has a permit (Montana DEQ Permit #MTR000363) to discharge stormwater into a ditch draining to Lake Helena. The permit was issued for April 2002 through September 2006. In 1999, the facility renovated the south drainage ditch and created a detention pond with 150,000 square feet of capacity capable of containing a 50-year storm event. Stormwater infiltrates into the groundwater through this system. Between June 2002 and December 2004, there were no reported discharge events from the detention pond.

1.3 Non-Permitted Discharges

The following sections summarize the non-permitted point sources in the Lake Helena watershed.

1.3.1 Eastgate Subdivision (No DEQ Permit)

The Eastgate Subdivision Homeowners Association is located approximately one mile northeast of the city of East Helena in the subwatershed draining directly to the Helena Valley irrigation system, and ultimately Lake Helena. The subdivision currently operates a wastewater treatment system consisting of two mechanically aerated ponds that are designed to treat 0.15 MGD. Montana DEQ does not require a permit from this facility. Final effluent is disposed via irrigation to cropland, and this system is currently in compliance and meeting design specifications. The concentrations reported for total nitrogen and total phosphorus after stabilization are of 14.5 mg-N/L and 5 mg-P/L. No groundwater monitoring data are available.

1.3.2 Treasure State Acres Subdivision (No DEQ Permit)

The Treasure State Acres Subdivision is located approximately 1.5 miles north of the city of Helena (Helena Valley) in the Prickly Pear Creek subwatershed. There is currently a wastewater treatment system consisting of two storage ponds treating 0.1 MGD. Montana DEQ does not require a permit from this facility. There is currently insufficient pond storage capacity for the population served by the ponds. Therefore, full treatment is unlikely. Effluent is applied to cropland. However, there is insufficient pond storage capacity for the population served, so full treatment is unlikely. The Treasure State system is designed to discharge via land application and should have no seepage or direct discharge. If this system were operating as designed, annual TN loads would decrease from 0.07 to 0.04 mt/yr. The TP loads would decrease from 0.11 to 0.07 mt/yr.

1.3.3 Tenmile and Pleasant Valley Subdivisions (No DEQ Permit)

The Tenmile and Pleasant Valley subdivisions are located approximately 1.5 miles north of the City of Helena (Helena Valley) in the Prickly Pear Creek subwatershed, and just north of the Treasure State Acres subdivision. Tenmile and Pleasant Valley are served by a 0.09 MGD wastewater treatment system consisting of four ponds designed for total retention with disposal via evaporation. Montana DEQ does not require a permit from this facility. Though current wastewater flows should fill all four ponds, only one pond currently fills. Water balance calculations performed by the authors of the Facility Plan conclude that excessive seepage is occurring from the ponds. Because of this, Montana DEQ is currently pursuing enforcement action against the subdivision (Jim Llyod, Personal Communications, September 27, 2005). It is assumed that 25 percent of the flow is discharged to the subsurface with concentrations typical of "stabilization pond effluent" and that 75 percent of the effluent is discharged to the subsurface at "after sedimentation" concentrations.

1.3.4 Leisure Village Mobile Home Park (No DEQ Permit)

The Leisure Village Mobile Home Park is located approximately 1.5 miles northeast of the city of Helena in the Helena Valley, and it is located in the subwatershed draining directly to Lake Helena. Four treatment/storage ponds receiving 0.1 MGD serve the Leisure Village Mobile Home Park. Montana DEQ does not require a permit from this facility. Only one pond currently fills, but waste flows are sufficient to fill all four ponds. It is assumed that 25 percent of the flow is discharged to the subsurface with concentrations typical of "stabilization pond effluent" and that 75 percent of the effluent is discharged to the subsurface at "after sedimentation" concentrations.

1.3.5 Mountain View Academy (No DEQ Permit)

The Mountain View Law Enforcement Academy is located approximately 3.5 miles north of the city of Helena in the subwatershed draining directly to Lake Helena. The academy currently possesses two small, facultative treatment ponds that treat 0.007 MGD. Montana DEQ does not require a permit from this facility. Effluent discharge occurs by evaporation, seepage, and direct discharge to Prickly Pear Creek. There is no evidence that the system is not operating as designed, so it is assumed that 100% of the flow discharges to Prickly Pear Creek with stabilization pond effluent values. No surface area information or actual flow measurements are available to account for evaporative losses.

1.3.6 Fort Harrison (No DEQ Permit)

The Fort Harrison treatment ponds are located approximately 1.8 miles northeast of the city of Helena in the Sevenmile Creek subwatershed. Prior to 2004, The Fort Harrison facility treated wastewater from Fort Harrison, the National Guard, and the VA Center/Hospital. At the time, Montana DEQ did not require a permit from this facility. Currently, the facility is closed. Prior to 2004, two 5-acre facultative treatment ponds received 0.07 MGD of wastewater.

1.4 City of Helena MS4 Stormwater Permit (MTR040003)

For areas with a population below 50,000, the federal Phase II Stormwater regulations require states to establish designation criteria for use in designating which small MS4s must develop storm water management programs. The State of Montana has decided that the City of Helena falls under the regulations of the small MS4 program, and therefore requires a stormwater permit. Montana DEQ received the draft MS4 permit (#MTR040003) in March 2003. Currently, there are no permit limits for the city stormwater system.

On June 1, 2005, USEPA and PBS&J employees toured the stormwater system with personnel from the Helena Utility Maintenance Department. The purpose of the field assessment was to observe flows and outfalls throughout the city to better understand the Helena stormwater system. June 1, 2004 was one of the wettest days in 2004, and Helena received almost 1.5 inches of rain on this day. The tour was conducted after more than 0.75 inches of rain had fallen. The following paragraphs summarize the observed flows and outfalls from the tour.

The first sites visited were the main outfall locations of the Airport and Bull Run basins (numbers 1 to 3, see Figure 3). Water from both of these basins is ultimately discharged to the Prickly Pear subwatershed upstream of the Helena WWTP. The majority of stormwater runoff from the Bull Run basin is routed through the Airport settling ponds. The settling ponds appeared to retain quite a bit of flow, as very little water was seen exiting the Airport outfall locations (numbers 1 and 2 on Figure 3). The runoff from the two outlet locations viewed will ultimately discharge to groundwater and Prickly Pear Creek

Site 3 on Figure 3 is actually the outfall location of stormwater mixed from the Airport and Bull Run basins and the Davis Gulch Basin. Water was seen ponding here behind the Helena Valley Irrigation Canal (HVIDC). Jim Wilbur of the Lewis and Clark County Water Quality Protection District reported that on occasion this runoff will discharge to the Helena Valley Irrigation District Canal (HVIDC).

Site 4 on Figure 3 is the outfall location of stormwater from the Davis Gulch Basin. Stormwater is routed through a series of ponds, with very short retention times. Near the city boundary (Custer Avenue), the outfall flow from the "K-Mart ponds" is split and approximately half flows under the I-15 and along Custer Avenue to outfall location 3, while the remainder flows north along I-15 and discharges to the HVIDC. Ken Olsen of the Helena Valley Irrigation District reported that the City is aware of this situation and has been asked to address this matter. Some stormflow along Montana Avenue from the Last Chance Gulch Basin was seen ponding in fields on the north side of Custer Avenue. Based on patterns visible on the aerial photos, it is likely that this flow is eventually routed to discharge to the same location as the Davis Gulch Basin on the HVIDC at I-15.

Site 5 on Figure 3 is the major outfall location of stormwater from the Last Chance Gulch Basin. Stormwater south of this area is routed to Nature Park, an old placer mining site that now has a ravine that carries flow. Within less than a quarter of a mile at Cole Avenue, the surface flow discharges to groundwater.

Site 6 on Figure 3 is the major outfall location of stormwater from the West Basin. Stormwater in this basin is routed through a series of wetlands, with very short retention times. The wetlands outfall flows to Crystal Spring Creek, a natural spring that empties to Tenmile Creek. According the Jim Wilbur, the Crystal Spring area was once a large wetland. The County Fairgrounds, as well as the Dunbar subdivision and the developing Crystal Springs Subdivision are built on the historical wetland area. Crystal Spring drains flow from the Fairgrounds trough a series of pipes, including one from the duck pond. The Dunbar subdivision is one of the areas in the valley that has been reported as having groundwater contamination from nitrates. The lots are too small to relocate wells and septic systems, so the city is planning to annex the subdivision to city water and sewer. The new Crystal Springs Subdivision has a 200-foot setback requirement from Crystal Spring. The Water Quality Protection district is trying to find landowners downstream of the Crystal Springs Subdivision who are willing to restore some wetland area along the spring.

In October of 1999, the Lewis and Clark County Water Quality Protection District submitted a TMDL mini-grant report on the assessment of wetland treatment of stormwater runoff for the City of Helena. Included in the report are surface and groundwater samples collected in the Crystal Spring Area pre-runoff and during storm events.

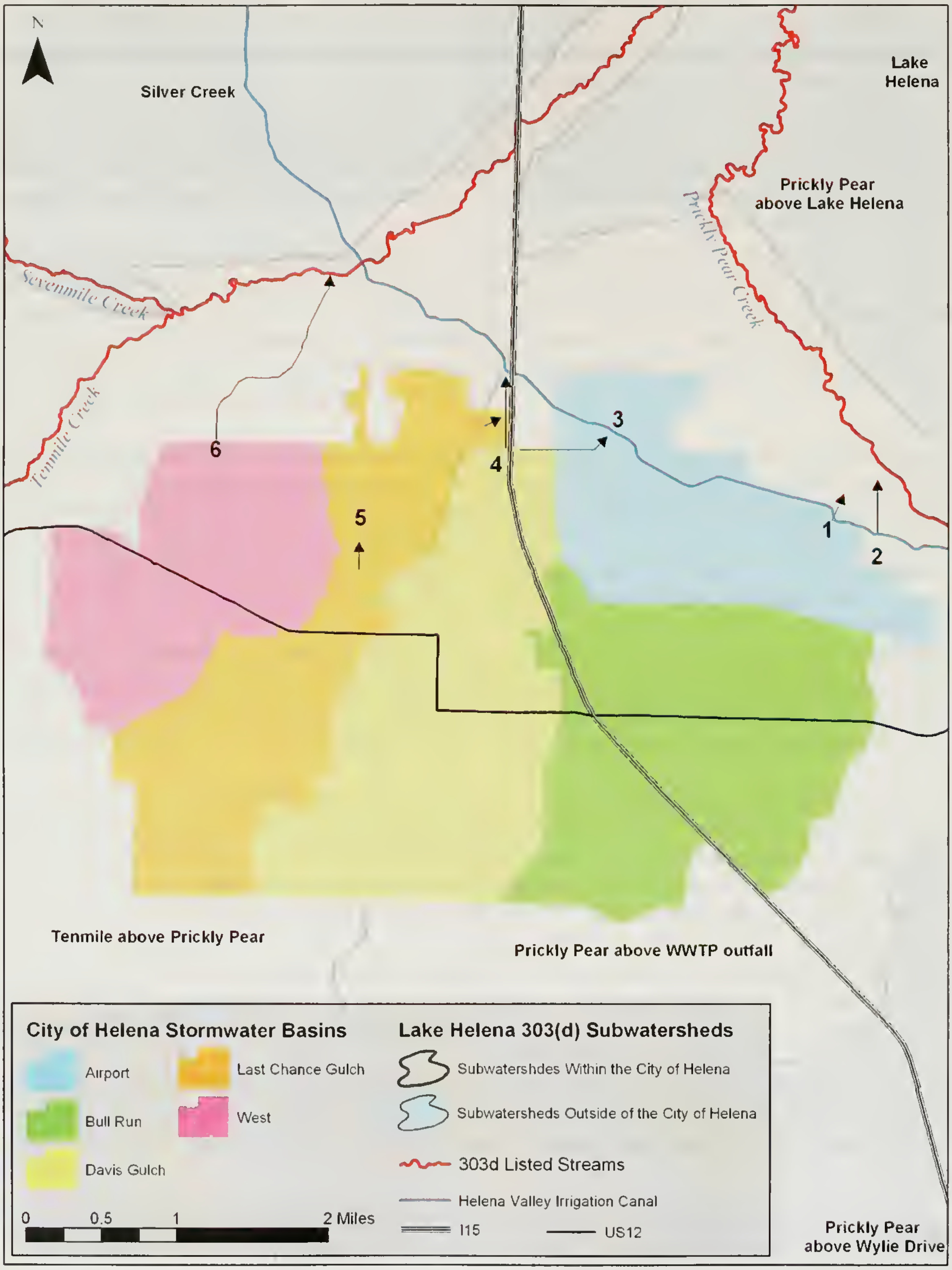

N
Silver Creek
Lake Helena
Prickly Pear above Lake Helena
Prickly Pear Creek
Sevenmile Creek
Tenmile Creek
1
2
3
4
5
6
Tenmile above Prickly Pear
Prickly Pear above WWTP outfall
Prickly Pear above Wylie Drive
City of Helena Stormwater Basins
Airport
Last Chance Gulch
Bull Run
West
Davis Gulch
Lake Helena 303(d) Subwatersheds
Subwatershdes Within the City of Helena
Subwatersheds Outside of the City of Helena
303d Listed Streams
Helena Valley Irrigation Canal
I15
US12
0
0.5
1
2 Miles

Figure 3. City of Helena Stormwater Basins with respect to the 303(d) Listed Streams and Subwatersheds

2.0 REFERENCES

Apollo Gold. 2005. Montana Tunnels Mine. Available online at http://www.apollogold.com/Apollo_Gold/RIGHT/operations/montanatunnels.htm

MDEQ. 2002. Final Environmental Assessment Montana Tunnels Mining Inc. Minor Amendment To Operating Permit 00113. Montana Department of Environmental Quality. Available online at: http://www.deq.mt.gov/ea/hardrock/tunnels/tunnels.asp.

Appendix F

LSPC Metals Modeling

Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report

August 31, 2006

Prepared for the Montana Department of Environmental Quality

Prepared by the U.S. Environmental Protection Agency,
Montana Operations Office
With Technical Support from Tetra Tech, Inc.
and PBS&J, Inc.

Project Manager: Ron Steg

CONTENTS

Contents 1
1.0 Introduction 1
2.0 Model Selection 5
  2.1 Technical Criteria 5
  2.2 Regulatory Criteria 5
  2.3 Loading Simulation Program C++ (LSPC) Model 6
3.0 Model Configuration 9
  3.1 Watershed Subdivision 9
  3.2 Stream Representation 11
  3.3 Land Use 13
    3.3.1 MRLC Land Use Data *13*
    3.3.2 Mining Land Use *16*
    3.3.3 Final Land Uses for LSPC *18*
  3.4 Point Sources 19
  3.5 Soils 20
  3.6 Meteorological Data 22
4.0 Model Calibration 25
  4.1 Hydrologic Calibration 25
    4.1.1 Hydrologic Calibration Methodology *25*
    4.1.2 Hydrologic Calibration Parameters *27*
    4.1.3 Evaluation of Hydrologic Calibration *30*
  4.2 Water Quality Calibration 37
    4.2.1 Water Quality Calibration Parameters *39*
    4.2.2 Evaluation of the Water Quality Calibration *40*
  4.3 Model Uncertainty and Use 53
5.0 LSPC Input Parameters 56
6.0 References 58

FIGURES

Figure 1-1. Metals impaired segments in the Lake Helena watershed. 3
Figure 3-1. Lake Helena subwatershed delineation. 10
Figure 3-2. Stream channel representation in the LSPC model. 11
Figure 3-3. Modified MRLC land use coverage. 15
Figure 3-4. Abandoned mines in the Lake Helena watershed. 17
Figure 3-5. Distribution of hydrologic soil groups. 21
Figure 3-6. Average maximum and minimum temperatures at the Helena Regional Airport weather station. 23
Figure 3-7. Average precipitation at the Helena Regional Airport weather station. 23
Figure 4-1. Location of hydrology and water quality calibration gages. 26
Figure 4-2. Snow simulation schematic. 28
Figure 4-3. Observed versus modeled flows at USGS gage 06061500 – Prickly Pear Creek near Clancy MT. 31
Figure 4-4. Composite analysis of observed versus modeled flow at USGS gage 06061500 – Prickly Pear Creek near Clancy MT. 33
Figure 4-5. Location of water quality monitoring stations in the Lake Helena watershed. 38
Figure 4-6. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Arsenic. 41
Figure 4-7. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Cadmium. 41
Figure 4-8. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Copper. 42
Figure 4-9. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Lead. 42
Figure 4-10. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Zinc. 43
Figure 4-11. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Arsenic. 44
Figure 4-12. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Cadmium. 44
Figure 4-13. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Copper. 45
Figure 4-14. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Lead. 45
Figure 4-15. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Zinc. 46
Figure 4-16. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Arsenic. 47
Figure 4-17. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Cadmium. 47
Figure 4-18. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Copper. 48
Figure 4-19. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Lead. 48
Figure 4-20. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Zinc. 49
Figure 4-21. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Arsenic. 50
Figure 4-22. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Cadmium. 50
Figure 4-23. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Copper. 51
Figure 4-24. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Lead. 51

Figure 4-25. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Zinc. 52

TABLES

Table 1-1. Waterbodies in the Lake Helena watershed that are impaired because of arsenic, cadmium, copper, lead, and/or zinc[1] 2
Table 2-1. Montana numeric surface water quality standards for metals used to develop the Lake Helena TMDLs. 6
Table 3-1. Drainage Area and Mean Elevation of the Lake Helena Subwatersheds 9
Table 3-2. Stream channel parameters for the LSPC model. 12
Table 3-3. Land use in the Lake Helena watershed. 14
Table 3-4. LCPS modeled land uses. 18
Table 3-5. Facility Level Information for Point Sources of Metals modeled with LSPC. 19
Table 4-1. Summary of snow module calibration. 29
Table 4-2. Error statistics for observed versus modeled flows at USGS gage 06061500 – Prickly Pear Creek near Clancy MT. 35
Table 4-3. Distribution Parameter and Average metals sediment concentration. 39
Table 4-4. Average IOQC and AOQC Parameter Values for Abandoned Mines. 39

1.0 INTRODUCTION

The Lake Helena Volume I report concluded that multiple segments in the Lake Helena watershed are impaired because of metals (i.e., arsenic, cadmium, copper, lead, and/or zinc), and therefore require total maximum daily loads (TMDLs) (see Table 1-1 and Figure 1-1). The TMDL process identifies the maximum load of a pollutant (i.e., metals) a waterbody is able to assimilate and fully support its designated uses, allocates portions of the maximum load to all sources, identifies the necessary controls that may be implemented voluntarily or through regulatory means, and describes a monitoring plan and associated corrective feedback loop to insure that uses are fully supported. Modeling is often used during the development of TMDLs to help with one or more of these tasks.

The purpose of this appendix is to explain the TMDL modeling approach and results for metals in the Lake Helena watershed. Metals modeling was conducted to help answer the following key questions:

- What is the extent to which current flow and in-stream metals concentrations have been affected by anthropogenic activities?
- What are the expected flow and metals conditions during periods for which no observed data are available?
- What are the existing metals loads from each subwatershed?
- What are the existing metals loads from each source category (i.e., point sources, abandoned mines, natural background)?
- What are allowable metals loads from each subwatershed and source category that will result in the attainment of water quality standards?
- What are the potential benefits of various control options?

The remainder of this document describes the model selection and calibration results. TMDLs for each impaired segment are then presented in the main Volume II document and in Appendix A.

Table 1-1. Waterbodies in the Lake Helena watershed that are impaired because of arsenic, cadmium, copper, lead, and/or zinc[1].

Segment	Waterbody ID	Cause of Impairment				
		Arsenic	Cadmium	Copper	Lead	Zinc
Clancy Creek from Headwaters to the Mouth	MT41I006_120	X	X	X	X	X
Corbin Creek from Headwaters to the Mouth	MT41I006_090	X	X	X	X	X
Golconda Creek, Headwaters to the Mouth	MT41I006_070		X		X	
Jennies Fork from Headwaters to Mouth	MT41I006_210				X	
Lake Helena	MT41I007_010	X			X	
Lump Gulch from Headwaters to the Mouth	MT41I006_130		X	X	X	X
Middle Fork Warm Springs Creek, Headwaters to Mouth	MT41I006_100	X	X		X	X
North Fork Warm Springs Creek, Headwaters to Mouth	MT41I006_180	X	X			X
Prickly Pear Creek from Headwaters to Spring Creek	MT41I006_060				X	
Prickly Pear Creek from Highway 433 Crossing to Helena Waste Water Treatment Plant Discharge	MT41I006_030	X			X	
Prickly Pear Creek from Lump Gulch to Montana Highway 433 Crossing	MT41I006_040	X	X	X	X	X
Prickly Pear Creek from Spring Creek to Lump Gulch	MT41I006_050		X		X	X
Prickly Pear Creek from the Helena Waste Water Treatment Plant Discharge Ditch to Lake Helena	MT41I006_020	X	X		X	
Sevenmile Creek from Headwaters to the Mouth	MT41I006_160	X		X	X	
Silver Creek from Headwaters to the Mouth	MT41I006_150	X				
Spring Creek from Corbin Creek to the Mouth	MT41I006_080	X	X	X	X	X
Tenmile Creek from the Helena Public Water Supply Intake Above Rimini to the Helena Waste Water Treatment Plant.	MT41I006_142	X	X	X	X	X
Tenmile Creek from the Helena Wt Plant to the Mouth	MT41I006_143	X	X	X	X	X
Tenmile Creek, Headwaters to the Helena Public Water Supply Intake Above Rimini	MT41I006_141	X	X	X	X	X
Warm Springs Creek from the Middle Fork to the Mouth	MT41I006_110	X	X		X	X

[1] This table includes waterbodies that are impaired by metals, as determined by the Lake Helena Volume I Report. See Volume I for a discussion of the 303(d) listings and updated metals assessments for all waterbodies in the Lake Helena watershed.

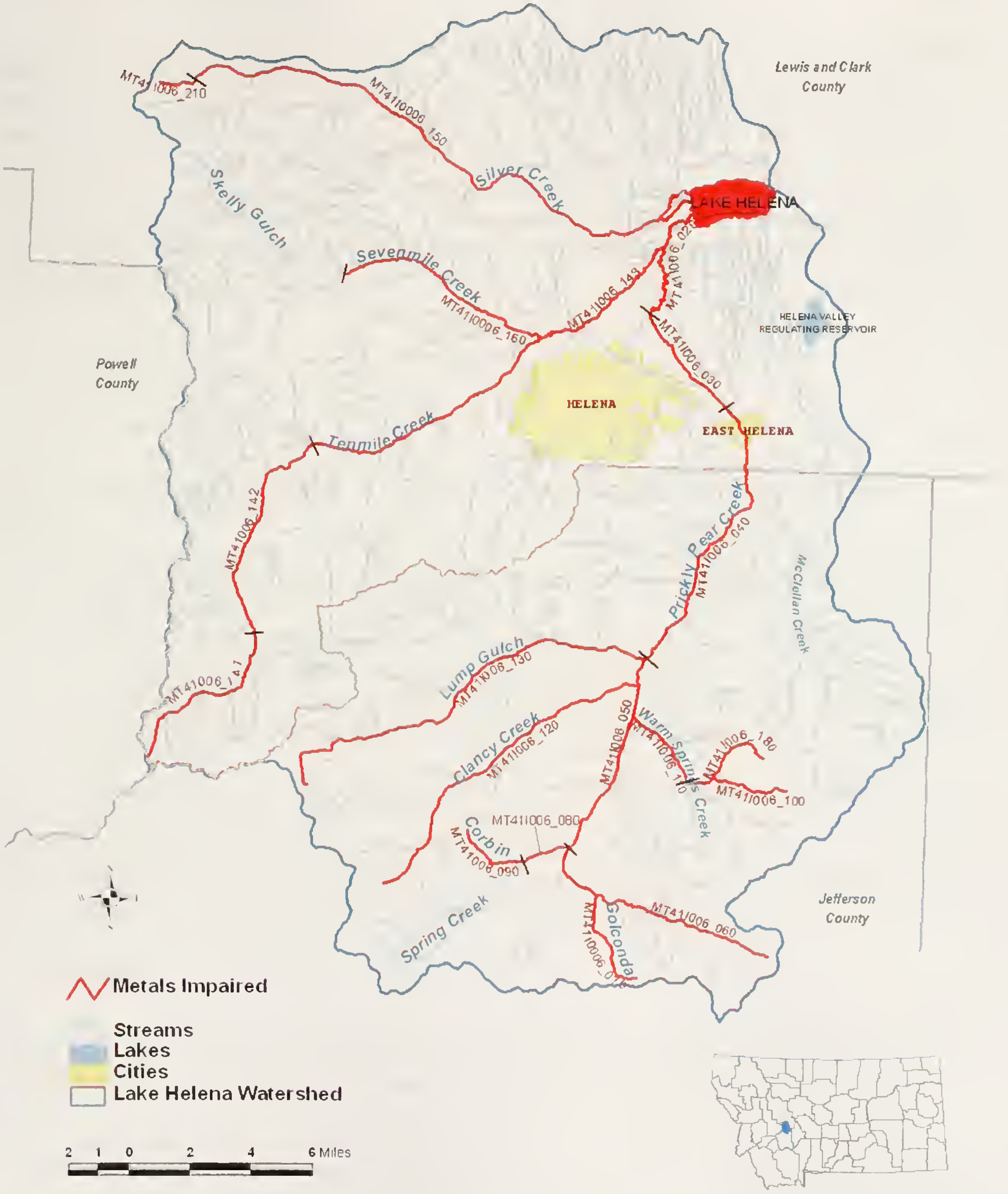


Figure 1-1. Metals impaired segments in the Lake Helena watershed.

2.0 MODEL SELECTION

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models are also capable of simulating in-stream processes using the land-based and subsurface calculations as input. Once a model has been adequately set up and calibrated for a watershed it can be used to quantify the existing loading of pollutants from subwatersheds or from land use categories and also can be used to assess the impacts of a variety of "what if" scenarios. The following criteria were considered and addressed in selecting an appropriate watershed model for the Lake Helena TMDL Planning Area:

- Technical Criteria
- Regulatory Criteria

2.1 Technical Criteria

The following technical factors were critical to selecting an appropriate watershed model for metals:

- The model should be able to address the pollutants of concern (e.g., arsenic, cadmium, copper, lead, and zinc).
- The model should be able to address a watershed with primarily rural land uses.
- The model should be appropriate for simulating large watersheds.
- The model should provide adequate time-step estimation of flow and not over-simplify storm events to provide accurate representation of rainfall events/snowmelt and resulting peak runoff.
- The model should be capable of simulating various pollutant transport mechanisms (e.g., groundwater contributions, sheet flow, etc.).
- The model should include an acceptable snowmelt routine.
- The model should be flexible enough to accommodate issues such as the arid nature of the watershed and the extensive amount of irrigation activities.

2.2 Regulatory Criteria

Regulatory criteria were also a key consideration in selecting an appropriate watershed model. A streams assimilative capacity is determined through adherence to numeric water quality standards. Table 2-1 summarizes the metals water quality standards applicable to the Lake Helena watershed. These tables indicate that the arsenic, cadmium, copper, lead, and zinc standards are applied as both chronic (4-day average) and maximum "not-to-exceed" values. The selected model therefore needed to be able to provide output that can be directly compared to these standards. For example, some models only provide annual or monthly output and would therefore be inadequate for assessing compliance with the component of Montana's standard that is expressed as an instantaneous maximum.

Table 2-1. Montana numeric surface water quality standards for metals used to develop the Lake Helena TMDLs.

Parameter	Aquatic Life (acute) (μg/L)[a]	Aquatic Life (chronic) (μg/L)[b]	Human Health (μg/L)[a]
Arsenic (TR)	340	150	10 [d]
Cadmium (TR)	1.05 at 50 mg/L hardness[c]	0.16 at 50 mg/L hardness[c]	5
Copper (TR)	7.3 at 50 mg/L hardness[c]	5.2 at 50 mg/L hardness[c]	1,300
Lead (TR)	82 at 100 mg/L hardness[c]	3.2 at 100 mg/L hardness[c]	15
Zinc (TR)	67 at 50 mg/L hardness[c]	67 at 50 mg/L hardness[c]	2,000

Note: TR = total recoverable.
[a] Maximum allowable concentration.
[b] No 4-day (96-hour) or longer period average concentration may exceed these values.
[c] The standard is dependent on the hardness of the water, measured as the concentration of $CaCO_3$ (mg/L) (see the Montana DEQ Circular WQB-7 for the equations for calculating standards).
[d] The human health standard for arsenic is currently 18 μg/L, but will change to 10 μg/L in 2006.

2.3 Loading Simulation Program C++ (LSPC) Model

Based on the considerations described in Sections 2.1 and 2.2, the Loading Simulation Program C++ (LSPC) was selected for modeling metals in the Lake Helena watershed. LSPC is essentially a re-coded C++ version of the Hydrologic Simulation Program Fortran (HSPF) model. LSPC integrates a geographical information system (GIS), comprehensive data storage and management capabilities, the original HSPF algorithms, and a data analysis/post-processing system into a convenient PC-based windows interface. LSPC's algorithms are identical to a subset of those in the HSPF model. LSPC is currently maintained by the EPA Office of Research and Development in Athens, Georgia. A brief overview of the HSPF model is provided below and a detailed discussion of HSPF simulated processes and model parameters is available in the HSPF User's Manual (Bicknell et al. 1996).

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970's. During the past several years it has been used to develop hundreds of USEPA-approved TMDLs and it is generally considered the most advanced hydrologic and watershed loading model available. The hydrologic portion of HSPF is based on the Stanford Watershed Model (Crawford and Linsley, 1966), which was one of the pioneering watershed models developed in the 1960's. The HSPF framework is developed in a modular fashion with many different components that can be assembled in different ways, depending on the objectives of the individual project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes.

All three of these modules include many submodules that calculate the various hydrologic and water quality processes in the watershed. Many options are available for both simplified and complex process formulations. Spatially, the watershed is divided into a series of subbasins representing the drainage areas that contribute to each of the stream reaches. These subbasins are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into the pervious (PERLND) and impervious

(IMPLND) fractions. The stream network (RCHRES) links the surface runoff and groundwater flow contributions from each of the land segments and subbasins and routes them through the waterbodies using storage routing techniques. The stream model includes precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals can also be accommodated. The stream network is constructed to represent all of the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Like the watershed components, several options are available for simulating water quality in the receiving waters. The simpler options consider transport through the waterways and represent all transformations and removal processes using simple first-order decay approaches. This method is appropriate for the pollutants of concern (i.e., arsenic, cadmium, copper, lead, and zinc) using decay to represent the net loss due to all processes such as settling and adsorption. The framework is flexible and allows different combinations of constituents to be modeled depending on data availability and the objectives of the study.

Advantages to choosing LSPC for this application include:

- Simulates all of the necessary constituents and applies to rural watersheds
- A comprehensive modeling framework using the proposed LSPC approach facilitates development of TMDLs not only for this project, but also for potential future projects to address other impairments throughout the basin (e.g., nutrients)
- The time-variable nature of the modeling enables a straightforward evaluation of the cause-effect relationship between source contributions and waterbody response and direct comparison to relevant water quality criteria.
- The proposed modeling tools are free and publicly available. This is advantageous for distributing the model to interested stakeholders and amongst government agencies.
- The model simulates both surface and subsurface impacts to flow and water quality.
- LSPC provides storage of all geographic, modeling, and point source permit data in a Microsoft Access database and text file formats to provide for efficient manipulation of data
- LSPC presents no inherent limitations regarding the size and number of watersheds and streams that can be modeled.
- LSPC provides post-processing and analytical tools designed specifically to support TMDL development and reporting requirements

The setup and calibration of the Lake Helena LSPC watershed model are described in Sections 3.0 and 4.0, respectively.

3.0 MODEL CONFIGURATION

Configuration of the LSPC model involved five major components: watershed subdivision, stream representation, meteorological data, land use representation, and hydrologic and pollutant representation. These components provide the basis for the model's ability to estimate flow and pollutant loadings and are described in greater detail below.

3.1 Watershed Subdivision

LSPC calculates watershed processes based on user defined, hydrologically connected subwatersheds. Subwatersheds were delineated in the Lake Helena TMDL Planning Area to meet the goals of the project. Output was desired at the mouth of each 303(d) listed segment. Therefore, subwatersheds were first delineated to those segments. Subwatersheds were next delineated to flow and water quality gages to facilitate model calibration. Finally, subwatersheds were delineated to areas of concern, such as political boundaries or areas with significant sources. Using this method, 22 subwatersheds were defined for the Lake Helena watershed (Figure 3-1). Table 3-1 summarizes basic characteristics of each watershed (subwatershed area, mean elevation, and corresponding 303(d) segment ID).

Table 3-1. Drainage Area and Mean Elevation of the Lake Helena Subwatersheds

Subwatershed	Watershed Area (ac)	Mean Elevation (m)	Corresponding Waterbody Key
Clancy Creek	21,140	1757.5	MT41I006_120
Corbin Creek	1,715	1685.2	MT41I006_090
Golconda Creek	1,887	1962.2	MT41I006_070
Jackson Creek	2,148	1924.2	MT41I006_190
Jennies Fork	670	1855.5	MT41I006_210
Overland flow to Lake Helena	36,834	1196.0	Overland flow
Lump Gulch	27,762	1722.3	MT41I006_130
Middle Fork Warm Springs	2,180	1796.9	MT41I006_100
Middle Tenmile Creek	24,701	1730.0	MT41I006_142
North Fork Warm Springs Creek	1,343	1721.7	MT41I006_180
Prickly Pear above Spring Creek	17,070	1866.7	MT41I006_060
Prickly Pear above Lake Helena	4,201	1134.6	MT41I006_020
Prickly Pear above Lump Gulch	16,275	1581.2	MT41I006_050
Prickly Pear above WWTP outfall	12,431	1294.0	MT41I006_030
Prickly Pear above Wylie Drive	47,176	1554.9	MT41I006_040
Sevenmile Creek	24,883	1527.6	MT41I006_160
Silver Creek	59,013	1355.4	MT41I006_150
Skelly Gulch	7,834	1700.6	MT41I006_220
Spring Creek	11,620	1758.4	MT41I006_080
Tenmile above Prickly Pear	48,786	1455.1	MT41I006_143
Upper Tenmile Creek	14,106	2068.3	MT41I006_141
Warm Springs Creek	9,670	1688.2	MT41I006_110
Total Watershed Area	*393,445*	*NA*	*NA*

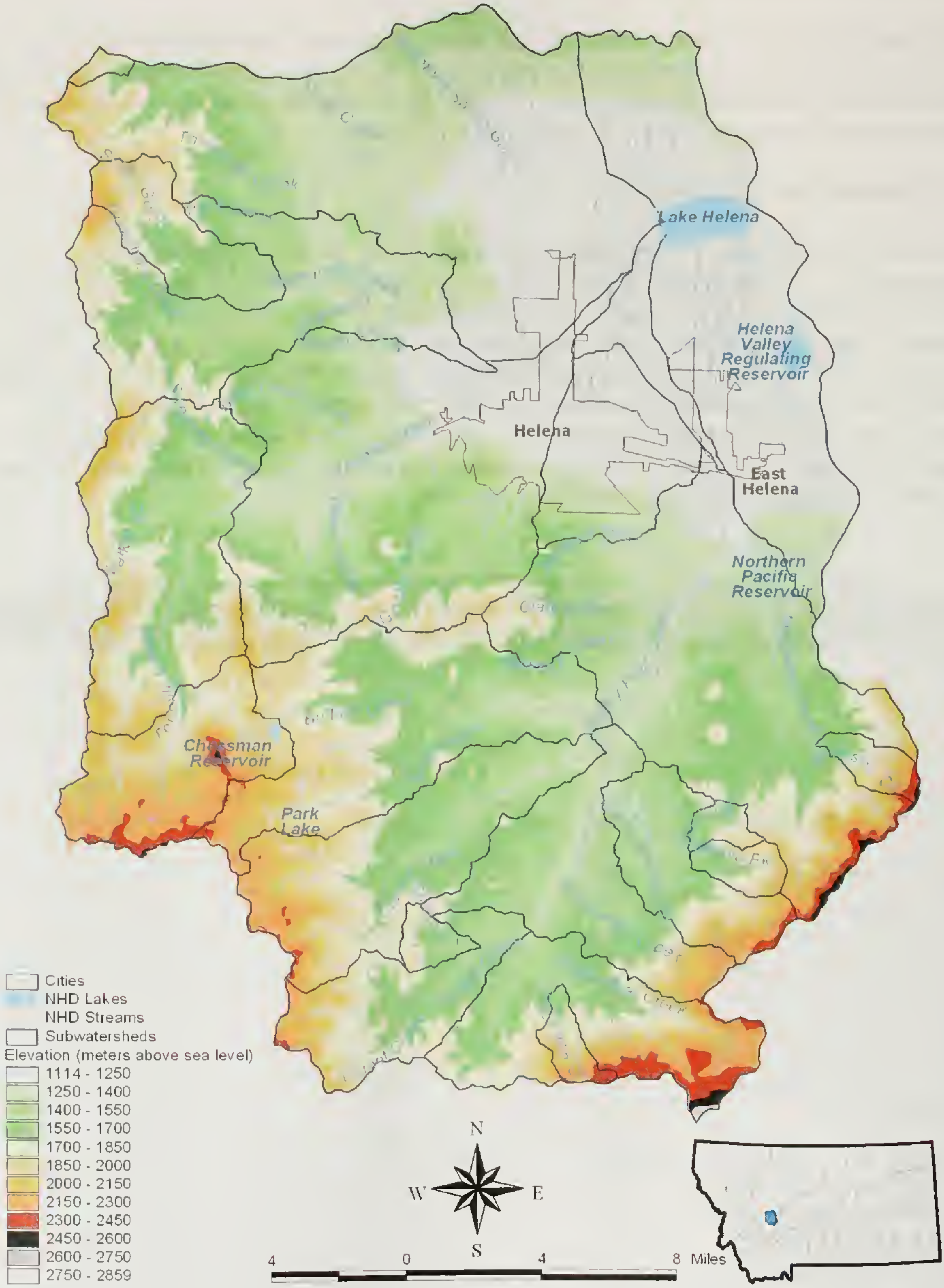


Figure 3-1. Lake Helena subwatershed delineation.

3.2 Stream Representation

Each delineated subwatershed in the LSPC model (see Section 3.1) was conceptually represented with a single stream assumed to be a completely mixed, one-dimensional segment with a constant cross-section, as defined in Figure 3-2. The National Hydrography Dataset (NHD) stream reach network was used to determine the representative stream length for each subwatershed (Table 3-2). NHD data were obtained from the Montana Natural Resources Information System (NRIS) website (http://nris.state.mt.us/).

Once the representative reach was identified, reach slopes were calculated based on the 30-meter National Elevation Dataset for Montana (Montana State Library, 2002). Reach slope was calculated with the formula shown below. Stream lengths were obtained from the NHD dataset.

$$\frac{(UpstreamElevation - DownstreamElevation)}{\mathrm{Re}\,achLength}$$

Channel dimensions for a number of segments were available from field surveys. Assuming representative trapezoidal geometry for all streams, mean stream depth and channel width were estimated using regression curves that relate upstream drainage area to stream dimensions (Rosgen, 1996), and these estimates were compared with stream surveys at selected locations (Table 3-2). Rating curves consisted of a representative depth-outflow-volume-surface area relationship. Estimated Manning's roughness coefficients of 0.035 were applied to each representative stream reach based on typical literature values for natural streams.

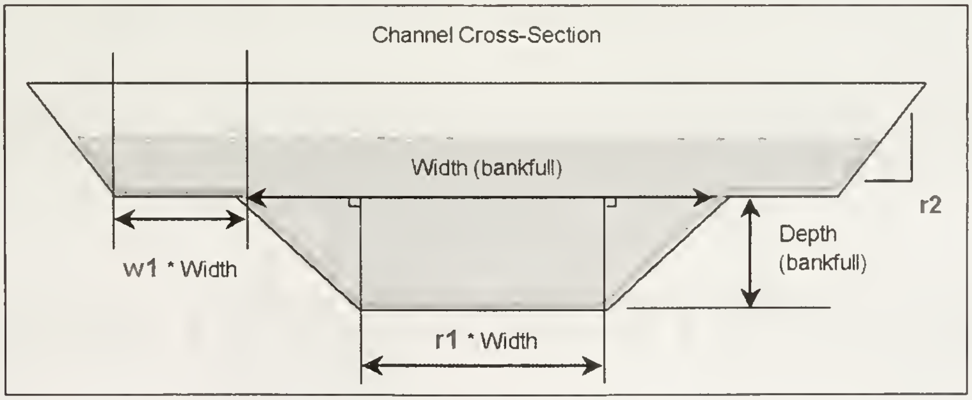


Figure 3-2. Stream channel representation in the LSPC model.

Table 3-2. Stream channel parameters for the LSPC model.

Stream/303(D) Segment	LSPC Watershed ID	Reach Length (Miles)	Bank Full Depth (Feet)	Longitudinal Channel Slope	Manning's Roughness Coefficient	Ratio Of Bottom Width To Bank Full Width	Side Slope Of Flood Plane	Flood Plane Width Factor
Lake Helena	100	2.41	4.16	0.00000	0.035	0.2	0.5	1.5
Prickly Pear above Lake Helena	200	5.97	3.94	0.00177	0.035	0.2	0.5	1.5
Prickly Pear above WWTP outfall	201	4.35	3.55	0.00594	0.035	0.2	0.5	1.5
Prickly Pear above Wylie Drive	202	10.51	3.50	0.02049	0.035	0.2	0.5	1.5
Jackson Creek	203	2.44	1.52	0.09379	0.035	0.2	0.5	1.5
Prickly Pear above Lump Gulch	300	7.05	3.08	0.01004	0.035	0.2	0.5	1.5
Lump Gulch	301	14.34	2.49	0.04085	0.035	0.2	0.5	1.5
Clancy Creek	302	11.49	2.36	0.03104	0.035	0.2	0.5	1.5
Warm Springs Creek	303	7.56	2.16	0.06500	0.035	0.2	0.5	1.5
Middle Fork Warm Springs	304	2.63	1.52	0.08203	0.035	0.2	0.5	1.5
North Fork Warm Springs Creek	305	2.45	1.39	0.08409	0.035	0.2	0.5	1.5
Spring Creek	306	8.35	2.16	0.04817	0.035	0.2	0.5	1.5
Corbin Creek	307	2.52	1.45	0.07739	0.035	0.2	0.5	1.5
Prickly Pear above Spring Creek	308	8.63	2.31	0.05753	0.035	0.2	0.5	1.5
Golconda Creek	309	3.65	1.48	0.15263	0.035	0.2	0.5	1.5
Tenmile above Prickly Pear	400	15.10	3.31	0.00923	0.035	0.2	0.5	1.5
Sevenmile Creek	401	14.39	2.57	0.02701	0.035	0.2	0.5	1.5
Skelly Gulch	402	7.75	1.95	0.05477	0.035	0.2	0.5	1.5
Middle Tenmile Creek	500	7.47	2.66	0.02086	0.035	0.2	0.5	1.5
Upper Tenmile Creek	501	6.79	2.18	0.05513	0.035	0.2	0.5	1.5
Silver Creek	600	21.58	2.88	0.02638	0.035	0.2	0.5	1.5
Jennies Fork	601	1.37	1.21	0.12322	0.035	0.2	0.5	1.5

3.3 Land Use

LSPC requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the watershed, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly related to land practices. Land use typically represents the primary unit for computing both water quantity and quality. In addition to the need for land use data in computing water quantity and quality, nonpoint source management decisions are also frequently based on land use related activity at the subwatershed level. Therefore, it is important to have a detailed land use representation with classifications that are meaningful for load allocation and load reduction. The following sections describe the source and rationale for the land use data used in the modeling effort.

3.3.1 MRLC Land Use Data

Existing land use and land cover in the Lake Helena watershed were determined from the Multi-resolution Land Consortium (MRLC) data and aerial photography. The MRLC data were derived from 30-meter resolution satellite imagery obtained during the early 1990s. The satellite images were classified and rectified by the consortium, and downloaded for this project from the Montana NRIS website. For the purpose of this analysis, the MRLC data were modified to reflect more current conditions in the Lake Helena watershed. Refer to Appendix C for detailed explanation of the creation of the modified MRLC land use coverage developed for all the Lake Helena watershed modeling exercises supporting TMDL development.

Figure 3-3 shows the modified land use data used in the LSPC modeling analysis. Undisturbed areas include full-growth forest, grassland, shrubland, and wetlands. Timber harvest includes recent clear-cut and regrowth areas. Dirt roads are unpaved roads built to legal specification. Illegal or non-system roads are those used for recreational purposes, such as dirt bikes, four wheelers, etc., and are assumed to be constructed without safety or environmental constraints. Quarries include only the portion of the site that does not drain to an internal storage pit. Agriculture includes row crops, small grains, fallow land, and pasture. Urban areas include residential, commercial, industrial, and major highways.

Table 3-3. Land use in the Lake Helena watershed.

Land Use	Existing (ac)	Natural (ac)
Bare Rock	84	84
Low Density Residential[a]	9,067	-
Quarries	234	-
Water	2,875	2,875
Transitional	1,853	-
Deciduous Forest	1,241	1,454
Evergreen Forest	154,204	171,484
Mixed Forest	36	36
Shrubland	37,014	46,787
Grassland	129,060	169,034
Pasture/Hay	14,892	-
Small Grains	16,925	-
Woody Wetland	1,270	1,270
Herbaceous Wetlands	421	421
Recent Clear-cut	522	-
Clear-cut Regrowth	3,571	-
Dirt Roads	3,326	-
Fallow	2,546	-
Row Crop	2,093	-
Non-system Roads	153	-
Low Density Residential[b]	2,950	-
Commercial/Industrial/Transportation	6,203	-
Urban/Recreational Grasses	1,001	-
Secondary Paved Roads	1,904	-
Total Watershed Area	**393,445**	**393,445**

[a] Represents developments detected during the orthophoto analysis or present in the original MRLC data set, with approximately 40 percent impervious area and 60 percent lawn.

[b] Low density residential areas having 40 percent impervious (house, barn, sheds), 24 percent pasture with poor ground cover (animal paddocks), and 36 percent lawn in good condition.

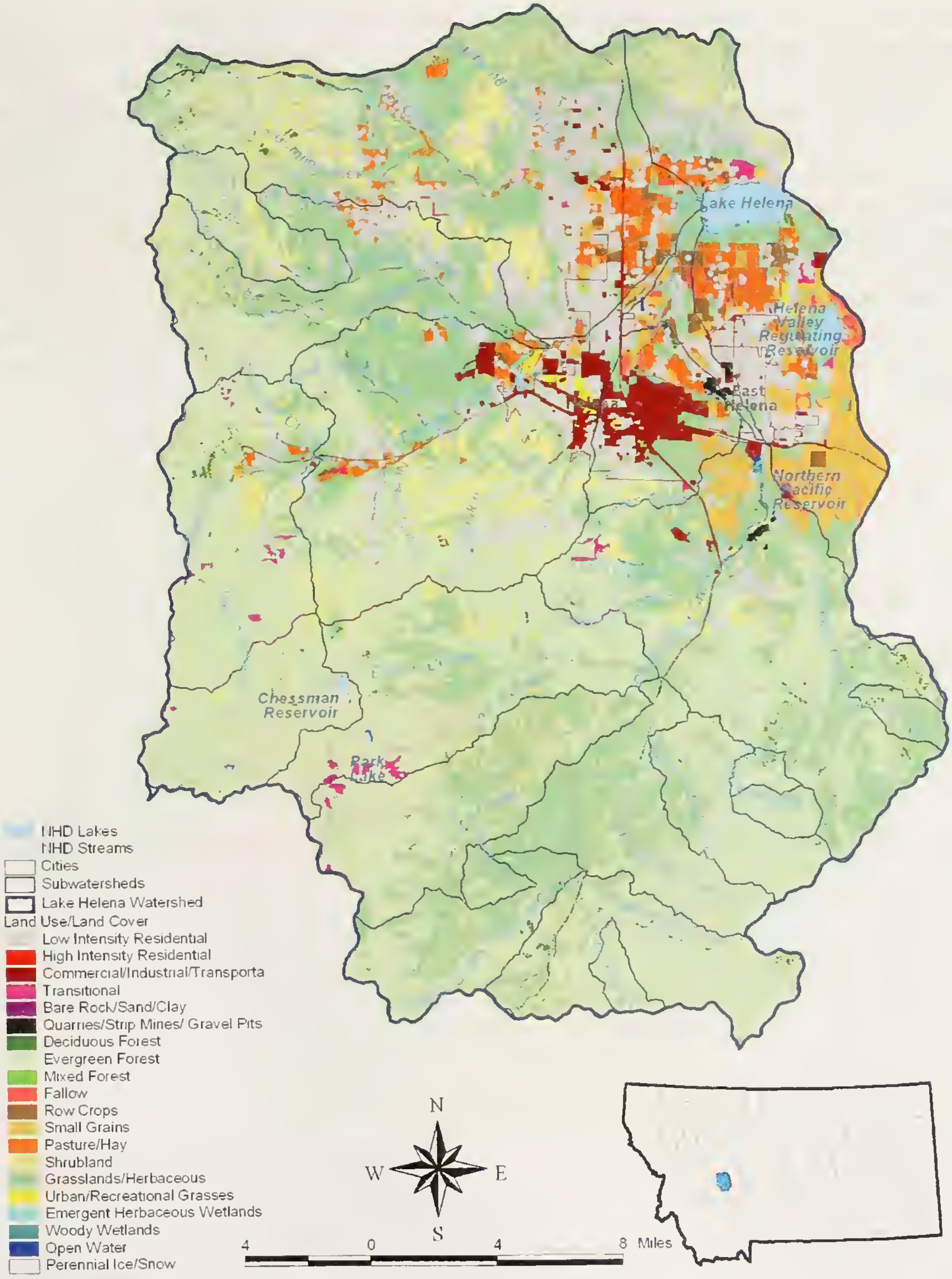


Figure 3-3. Modified MRLC land use coverage.

3.3.2 Mining Land Use

Specific data regarding the location and extent of disturbance from historical mining activities was not available from the MRLC land use coverage. These land-based sources were identified during the preliminary source assessment as critical sources that had to be addressed in the model. A GIS coverage including polygon outlines of priority abandoned hard rock mine sites inventoried by the Montana Department of Environmental Quality, Mine Waste Cleanup Bureau (1997) was used to determine the location and areas of disturbance of priority abandoned mines. In addition, the location of other inactive and abandoned mine sites was obtained from a GIS coverage published by the Montana State Library from data generated from the Abandoned Mines Bureau database in January of 1992. Because this coverage only shows the location of these mines, an area equal to the smallest priority mine was applied to each of the other mines to obtain an area for the model. Figure 3-4 shows the location of the modeled abandoned mines. Finally, two abandoned mine lands categories – Priority and Other – were added to the modeled land uses.

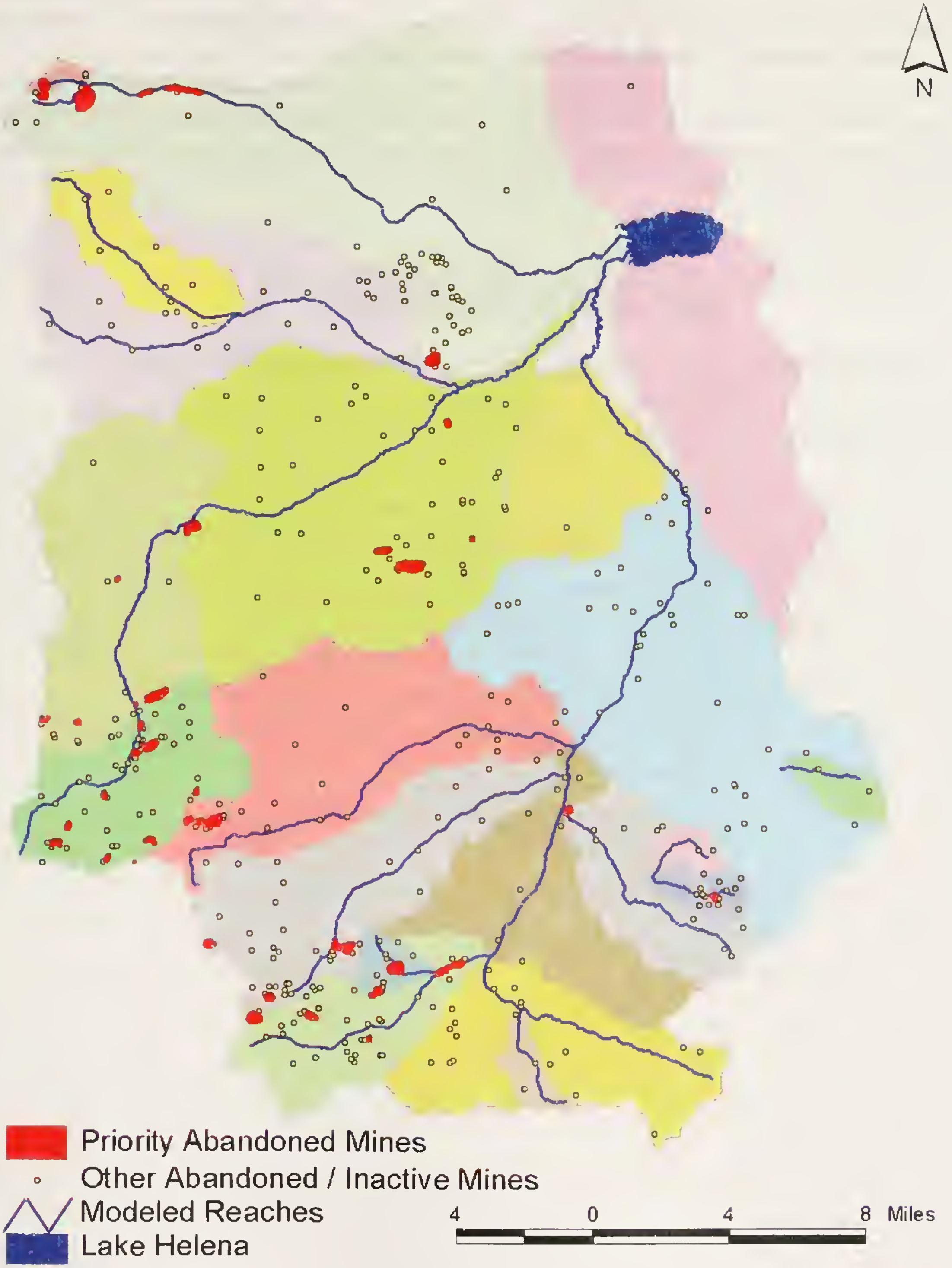


Figure 3-4. Abandoned mines in the Lake Helena watershed.

3.3.3 Final Land Uses for LSPC

For modeling purposes, MRLC land use classes having similar characteristics (i.e., infiltration rates, pollutant loads, etc.) were grouped together. The basis for the groupings was obtained from the MRLC land use definitions and best professional judgment. The final land use groupings provided the basis for estimating and distributing metals loads. Final land use categories included agriculture, shrubland, other abandoned mines, wetlands, priority abandoned mines, paved roads, dirt roads, permitted mines, non-system roads, quarries, full growth forest, timber harvest, grassland, and urban areas (Table 3-4).

Table 3-4. LCPS modeled land uses.

Land Use ID	LSPC Land Use Class	Acres
1	Forest	154,159
2	Grassland	131,525
3	Shrubland	37,015
4	Agriculture	36,456
5	Urban Areas	21,074
6	Paved Roads	1,904
7	Timber Harvest	4,093
8	Dirt Roads	3,326
9	Illegal Roads	153
10	Wetlands	1,691
11	Priority AML	1,272
12	Other AML	201
13	Permitted Mines	394
14	Quarries	182

3.4 Point Sources

Two facilities in the Lake Helena watershed currently have NPDES permits for metals – Montana Tunnels Mine (#MT0028428) and ASARCO (#MT0030147). Detailed information about these point sources can be found in Appendix E (Point Sources). The point sources were incorporated in the land use table as precipitation-driven permitted dischargers. The land infiltration properties were increased to represent settling ponds used to store site runoff. Modeled metals concentrations from these permitted facilities were set at permit limits. Permit limits for the Montana Tunnels facility are 0.29 mg/L for arsenic, 0.004 mg/L for cadmium, 0.01 mg/L for copper, 0.05 mg/L for lead, and 0.12 mg/L for zinc. ASARCO's permit limits are 1.140 mg/L for arsenic, 0.1374 mg/L for cadmium, 1.122 mg/L for copper, 0.239 mg/L for lead, and 0.77 mg/L for zinc. Table 3-5 shows the facility level information for these two point sources.

Table 3-5. Facility Level Information for Point Sources of Metals modeled with LSPC.

NPDES ID	MT0030147	MT0028428
Facility Name	ASARCO INC. (EAST HELENA)	MONTANA TUNNELS MINING, INC
Permit Type	STANDARD	STANDARD
Facility Type	INDUSTRIAL	INDUSTRIAL
SIC Description	PRMRY SMELT/NONFERROUS METALS	METAL ORES, NEC
County Name	LEWIS AND CLARK	JEFFERSON
Receiving Water	PRICKLY PEAR CREEK	PEN YAN CREEK
Latitude	+46 35 040	+46 21 260
Longitude	-111 55 110	-112 06 450

3.5 Soils

The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting (NRCS, 2001). Typically, clay soils that are poorly drained have the worst infiltration rates (D soils), while sandy soils that are well drained have the best infiltration rates (A soils). Hydrologic group data for the Lake Helena watershed were obtained from the State Soil Geographic (STATSGO) database. The data were summarized based on the major hydrologic group in the surface layers of the map unit (see Figure 3-5). Soils in the Lake Helena watershed are primarily classified as B and C, having moderate to slow infiltration rates when saturated. These hydrologic groups served as a starting point for the designation of infiltration and groundwater flow parameters during the LSPC setup.

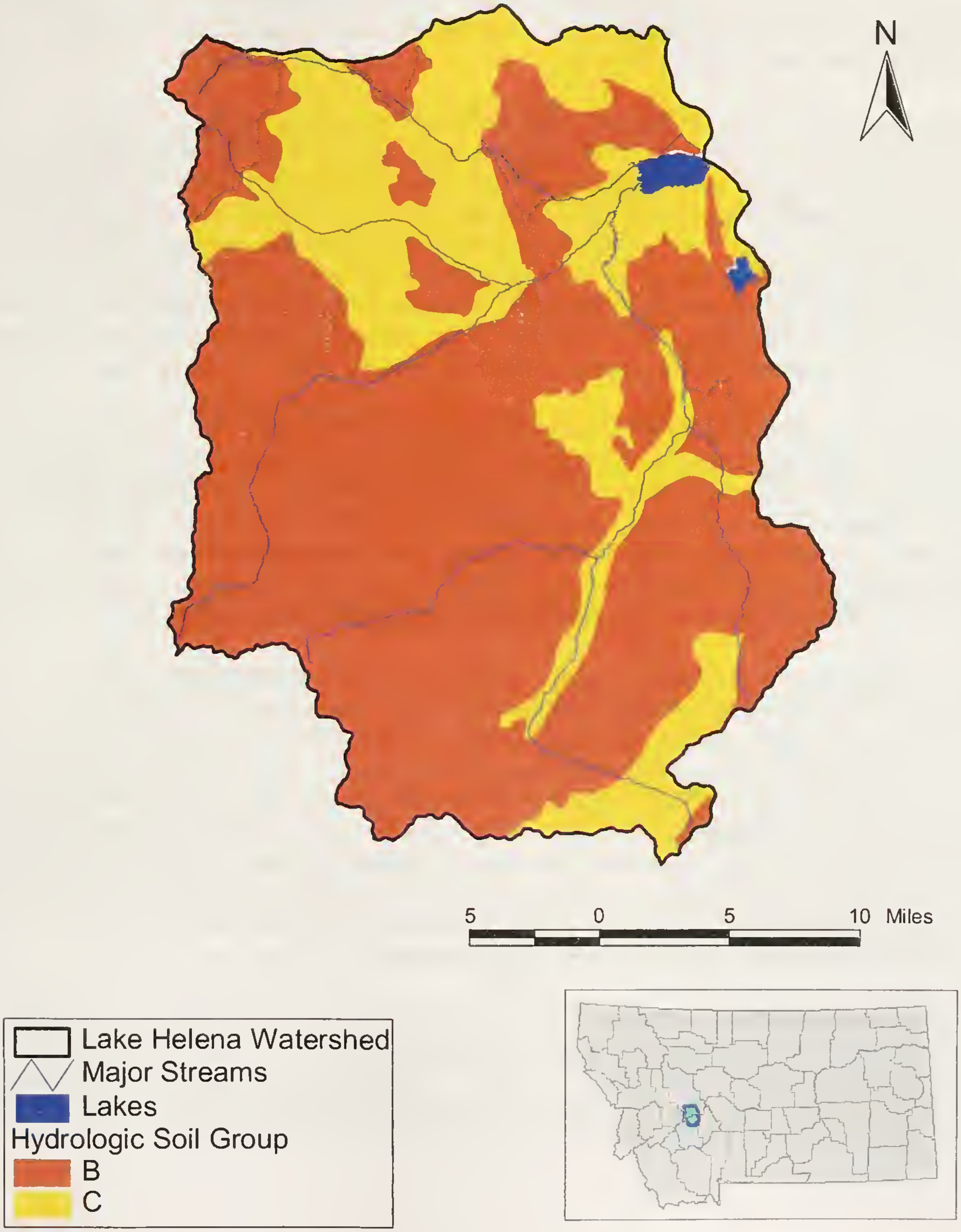


Figure 3-5. Distribution of hydrologic soil groups.

3.6 Meteorological Data

Hydrologic processes are time varying and depend on changes in environmental conditions such as precipitation, temperature, and wind speed. As a result, meteorological data are a critical component of watershed models.

Meteorological conditions are the driving force for non-point source transport processes in watershed modeling. Generally, the finer the spatial and temporal resolution available for meteorology, the more representative the simulation of associated watershed processes will be. At a minimum, precipitation and potential evapotranspiration are required as forcing functions for most watershed models. For the Lake Helena watershed, where the snowfall/snowmelt process is the most significant factor in watershed-wide hydrology, additional data were required for snow simulation. These data are temperature, dew point temperature, wind speed, and solar radiation. Upon reviewing the available weather data, it was concluded that there was only one adequate weather gage for the Lake Helena watershed – Helena Regional Airport Gage #244055.

Weather data from the Helena Regional Airport (elevation 1,167 m) was used to develop a 24-year input file with hourly time-series of data from January 1980 through December 2003. An hourly time step for weather data was required to properly reflect diurnal temperature changes (and the resulting influence on whether precipitation was modeled as rainfall or snow) and provide adequate resolution for rainfall/runoff intensity to drive erosion and water quality processes during storms or snowmelt events. Figure 3-6 and Figure 3-7 show average maximum and minimum daily temperatures and average daily precipitation at this location.

The mean elevation of each subwatershed was used to account for elevation effects on temperature and precipitation based on a comparison of mean annual precipitation and temperature at Austin, Montana (Coop ID 240375; elevation 1,493 m). For each meter increase in elevation, 0.03 cm/yr of precipitation were added and 0.0038 °C were subtracted from the daily average temperature. SNOTEL data were not adequate to develop daily weather inputs for the high elevation subwatersheds, but annual average precipitation at the Frohner station was used to validate the elevation adjustments cited above. In general, yearly precipitation at Frohner was more stable than at the airport. Even though elevation effects were accounted for, dry years at the airport generally result in an underestimation of precipitation in the high elevation subwatersheds and an over prediction in extremely wet years.

The Helena Regional Airport weather gage is located in the Helena Valley, and it is recognized here that this gage does not necessarily represent weather conditions throughout the entire 620 square mile watershed. This is particularly true in the high elevation regions of the watershed, where precipitation may be more than twice the precipitation in the Helena Valley. The lack of weather stations is believed to be the largest source of error in the LSPC model.

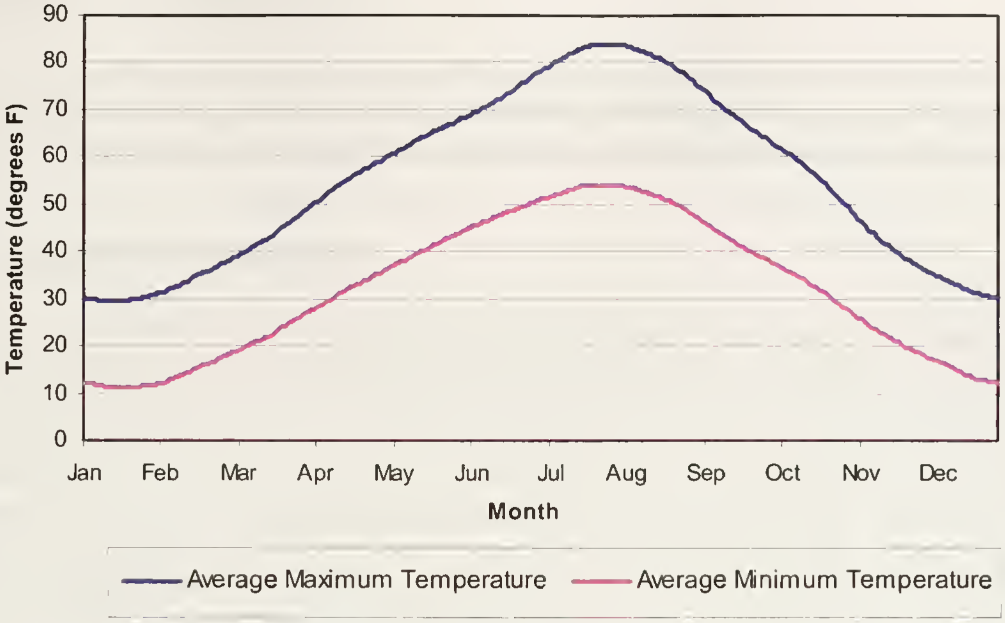


Figure 3-6. Average maximum and minimum temperatures at the Helena Regional Airport weather station.

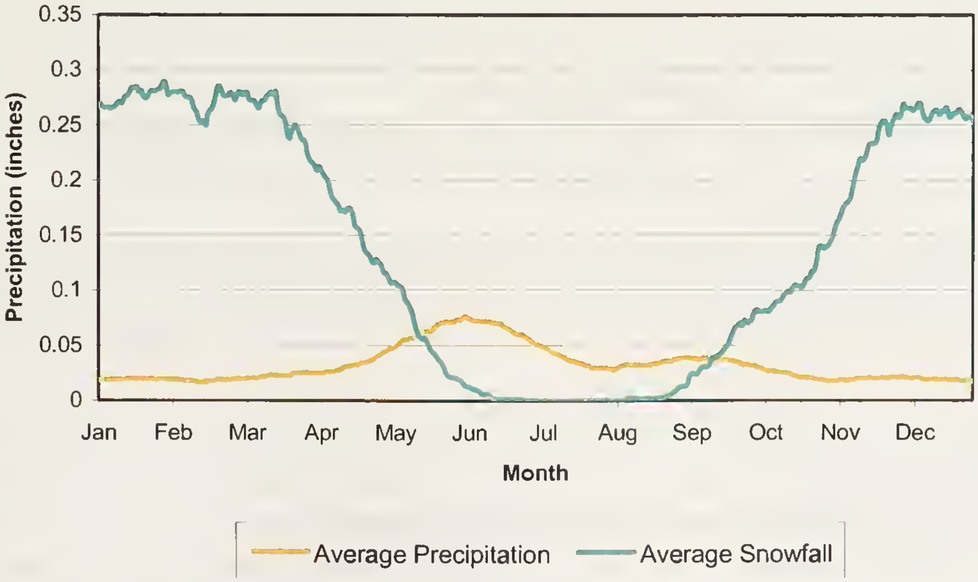


Figure 3-7. Average precipitation at the Helena Regional Airport weather station.

4.0 MODEL CALIBRATION

The model hydrology and water quality calibration process is described in this section. Background information on the locations of available flow and water quality data and the time periods of calibration are first presented, followed by a description of how key parameters were modified.

4.1 Hydrologic Calibration

Hydrologic calibration was performed after the initial model setup. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. For LSPC, calibration is an iterative procedure of parameter evaluation and refinement as a result of comparing simulated and observed values of interest. It is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, physical, and chemical characteristics of the watershed and compounds of interest. Calibration is based on several years of simulation to evaluate parameters under a variety of climatic conditions. The calibration procedure results in parameter values that produce the best overall agreement between simulated and observed flows throughout the calibration period.

4.1.1 Hydrologic Calibration Methodology

The hydrologic calibration process involved a comparison of observed data to modeled in-stream flow and an adjustment of key parameters. Calibration gages were selected based on (1) long term period of record, (2) recent data, and (3) location within the Lake Helena watershed. Only one calibration gage was used for the Lake Helena watershed model – USGS gage 06061500 (Prickly Pear Creek near Clancy, Montana). The Tenmile Creek gage (06063000) was then used to validate the results from the Prickly Pear Creek calibration.

Modeling parameters were varied within generally accepted bounds and in accordance with observed temporal trends and soil and land cover characteristics (see Section 4.1.2). An attempt was made to remain within the guidelines for parameter values set out in BASINS Technical Note 6 (USEPA, 2000).

Graphical results of model performance and error statistics were evaluated following each hydrologic simulation. Model parameters were adjusted following iterations to improve model performance. The parameters that were adjusted include those that account for the partitioning of surface versus subsurface flow, infiltration rate, surface and subsurface storage, evapotranspiration, and surface runoff. The full set of hydrologic parameters is available upon request from the Montana Department of Environmental Quality (see Section 5.0). A discussion of the key parameters and how they were adjusted is presented below in Section 4.1.2.

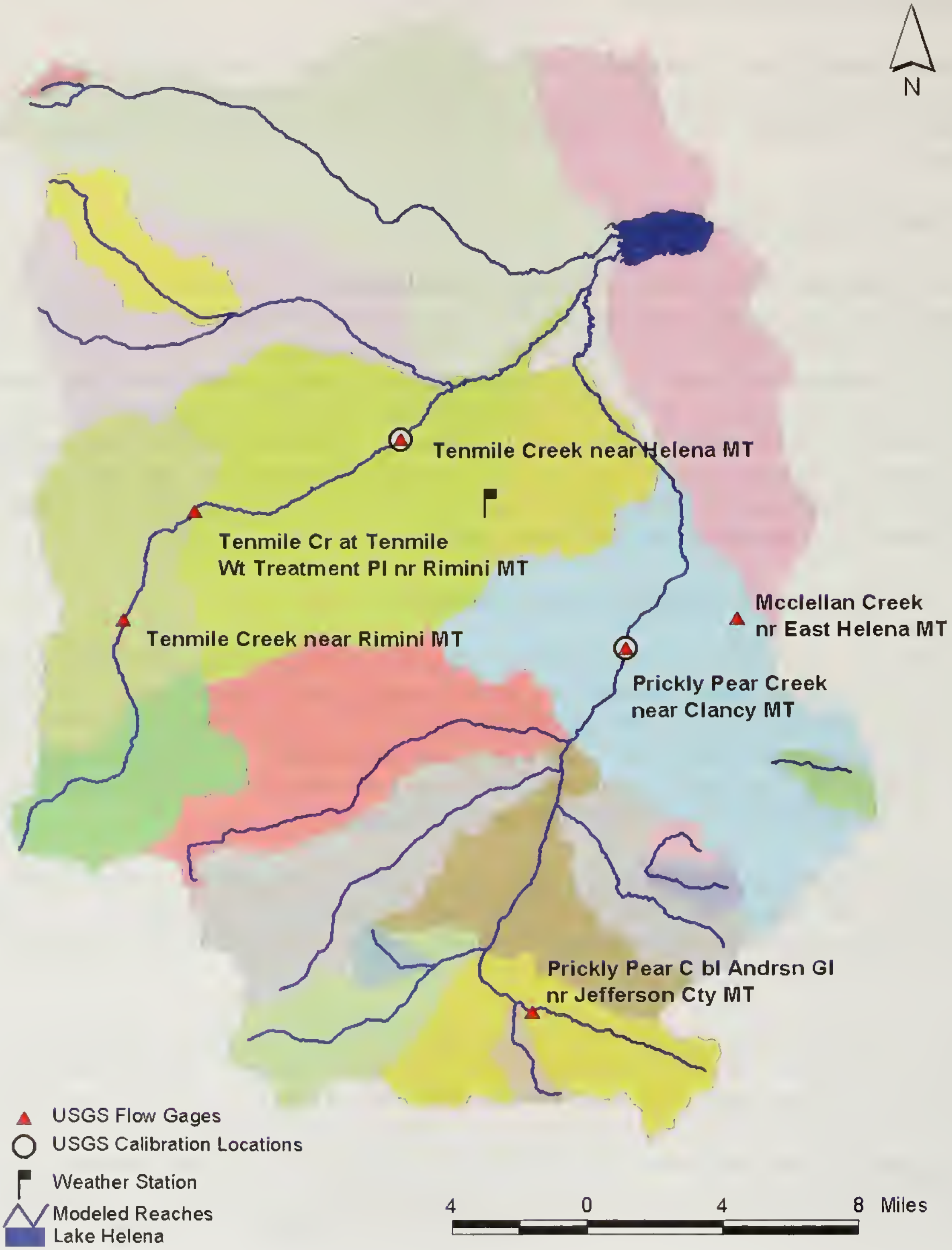


Figure 4-1. Location of hydrology and water quality calibration gages.

4.1.2 Hydrologic Calibration Parameters

The model performance is sensitive to the specification of the water-holding capacity of the soil profile (expressed through the nominal lower-zone storage, LZSN) and the infiltration rate index (INFILT), which together control the partitioning of water between surface and subsurface flow. The calibrated LZSN value was set at 6 inches. INFILT in HSPF is an *index* of infiltration rate and is not directly interpretable from measured field infiltration rates. BASINS Technical Note 6 recommends values in the range of 0.1 to 0.4 inches per hour for B soils, 0.05 to 0.1 inches per hour for C soils, and 0.01 to 0.05 inches per hour for D soils (USEPA, 2000). Values were re-optimized by starting from the center of the recommended ranges and modifying the value for each soil class proportionately. Final calibrated values ranged from 0.15 to 0.30 inches per hour.

Key parameters for the subsurface flow response include the ground water recession coefficient (AGWRC), and the interflow inflow and recession parameters (INTFW and IRC). AGWRC was set by optimizing model performance for baseflow recession. A final value of 0.999 (unitless) was determined for the Lake Helena watershed. Interflow recession should be fairly high in this landscape, and the interflow recession parameter was calibrated at 0.60 (unitless). Interflow was also calibrated at 0.60 (unitless).

Deep aquifer infiltration (DEEPFR) represents the fraction of infiltrating water that percolates to deep aquifers and is therefore "lost" water removed from the system. Within this watershed, DEEPFR was calibrated at 0.01 (unitless), suggesting that little water is lost from the system.

Monthly variability in hydrologic response was specified by setting monthly values the lower zone evapotranspiration parameter based on monthly weather conditions. Values specified are consistent with the range recommended in BASINS Technical Note 6 (0.1 to 0.9 unitless) (USEPA, 2000).

The parameters discussed above were the most sensitive in the hydrologic calibration, meaning that small changes had the largest effect on watershed hydrology. Other parameters, and their final calibrated values, are available upon request from the Montana Department of Environmental Quality (see Section 5.0).

Figure 4-2 is a schematic of how the snow process is simulated in LSPC. LSPC uses the Energy Balance method to simulate snowmelt contributions from the land surface derived from the fall, accumulation, and melting of snow (COE, 1956; Anderson Crawford, 1964; Anderson, 1968). The LSPC SNOW module uses information on atmospheric conditions to determine whether precipitation falls as rain or snow, how long the snowpack remains, and when snowpack melting occurs. Heat is transferred into or out of the snowpack through net radiation heat, convection of sensible heat from the air, latent heat transfer by moist air condensation on the snowpack, from rain, and through conduction from the ground beneath the snowpack. Melting occurs when the liquid portion of the snowpack exceeds its holding capacity and melted snow is added to the hydrologic cycle.

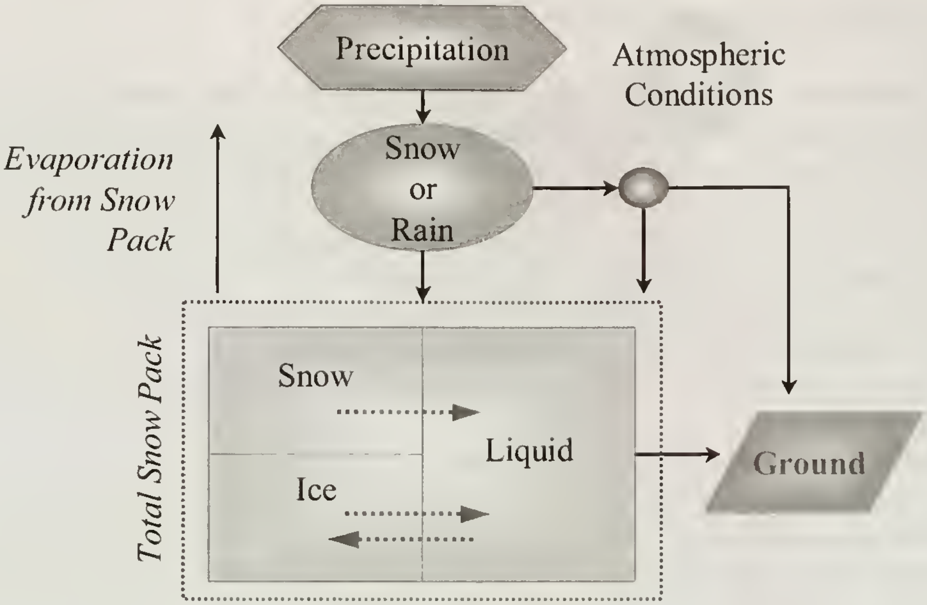


Figure 4-2. Snow simulation schematic.

Table 4-1 below summarizes the snow parameters and adjusted ranges for the Lake Helena watershed. Key calibration parameters for the winter snow simulation were revised from defaults during optimization and included the snow catch factor (SNOWCF, ratio that accounts for under-catch of snow in standard precipitation gages), the field adjustment parameter for heat accumulation in the snow pack (CCFACT), the maximum rate of snow melt by ground heating (MGMELT), and the difference between the mean elevation of a subwatershed and the gage elevation (ELDAT, to correct for temperature changes between the gage elevation and subwatershed elevation).

Table 4-1. Summary of snow module calibration.

Parameter	Description	Status	Default	Calibrated
ICEFG	Ice simulation switch, 1 = on or 0 = off	Turned on	1	1
FOREST	Forest land for winter transpiration (fraction)	By land use	N/A	0.1 – 0.8
LAT	Latitude of land segment (degrees)	From GIS	N/A	From GIS
MELEV	Mean elevation of land segment (ft)	From GIS	N/A	From GIS
ELDAT	Difference between MELEV and gage elevation (ft)	From GIS	N/A	From GIS
SHADE	Land shaded from solar radiation (fraction)	By land use	N/A	0.1 – 0.9
SNOWCF	Precipitation snow catch efficiency (multiplier)	By location	1.1 – 1.5	1.35
COVIND	Water equivalent for complete land coverage (in)	Constant	1.0 – 3.0	2.0
RDCSN	Density of new snow relative to water (in/in)	Constant	0.1 – 0.2	0.15
TSNOW	Air temperature for snowfall (degrees F)	By location	31 – 33	32.0
SNOEVP	Snowpack sublimation coefficient (unitless)	Constant	0.1 – 0.15	0.15
CCFACT	Condensation/convection coefficient (unitless)	By location	1.0 – 2.0	2.0
MWATER	Maximum water content of snow (in/in)	Constant	0.01 – 0.05	0.01
MGMELT	Maximum ground snowmelt rate (in/day)	Constant	0.01 – 0.03	0.01

4.1.3 Evaluation of Hydrologic Calibration

Hydrologic calibrations were evaluated by using a time series comparison of daily, monthly, seasonal, and annual values; storm events, low flows and high flows. Composite comparisons (e.g., average monthly values over the period of record) were also made. All of these comparisons must be evaluated for a proper calibration of hydrologic parameters.

4.1.3.1 Graphical Comparisons

Graphical comparisons are extremely useful for judging the results of model calibration because time-variable plots of observed versus modeled flow provide insight into the model's representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. Graphical comparisons consisted of time series plots of observed and simulated values for flows, observed versus simulated scatter plots with a 45^o linear regression line displayed, and observed versus simulated seasonal flows.

Figure 4-3 shows the observed data and graphical calibration model results for station 06061500 (Prickly Pear Creek near Clancy, Montana). The first plot (upper left) shows monthly-average simulated flow versus monthly average observed flow. The closer the data comes to the 45° angle line, the better the two data sets match. The plot suggests that some months are well correlated, and others are not. The plot does not provide information about which months are well or poorly calibrated. The second plot (upper right) shows the water balance between the observed and simulated monthly flows. In this plot, the 50 percent line indicates that the observed and modeled flows are equal. As shown in the graph, the water balance varies from month to month, but generally varies about the 50 percent line. This suggests that as a whole (all months), monthly flows are well calibrated. The third graph (middle center) shows a time series of average modeled and observed flow. Average flows are well correlated during the baseflow months (October through March). However, it appears that snowmelt is less calibrated. The initial simulated snowmelt, occurring in April of each year, is well correlated with the observed snowmelt. Later in the season (July and August), snowmelt is still occurring in the modeled flows, but not in the observed flows. The fourth plot (bottom center) verifies this. The fourth plot also suggests that there are errors with the storm event simulation. This is expected because of the limited weather data, and lack of high elevation weather stations.

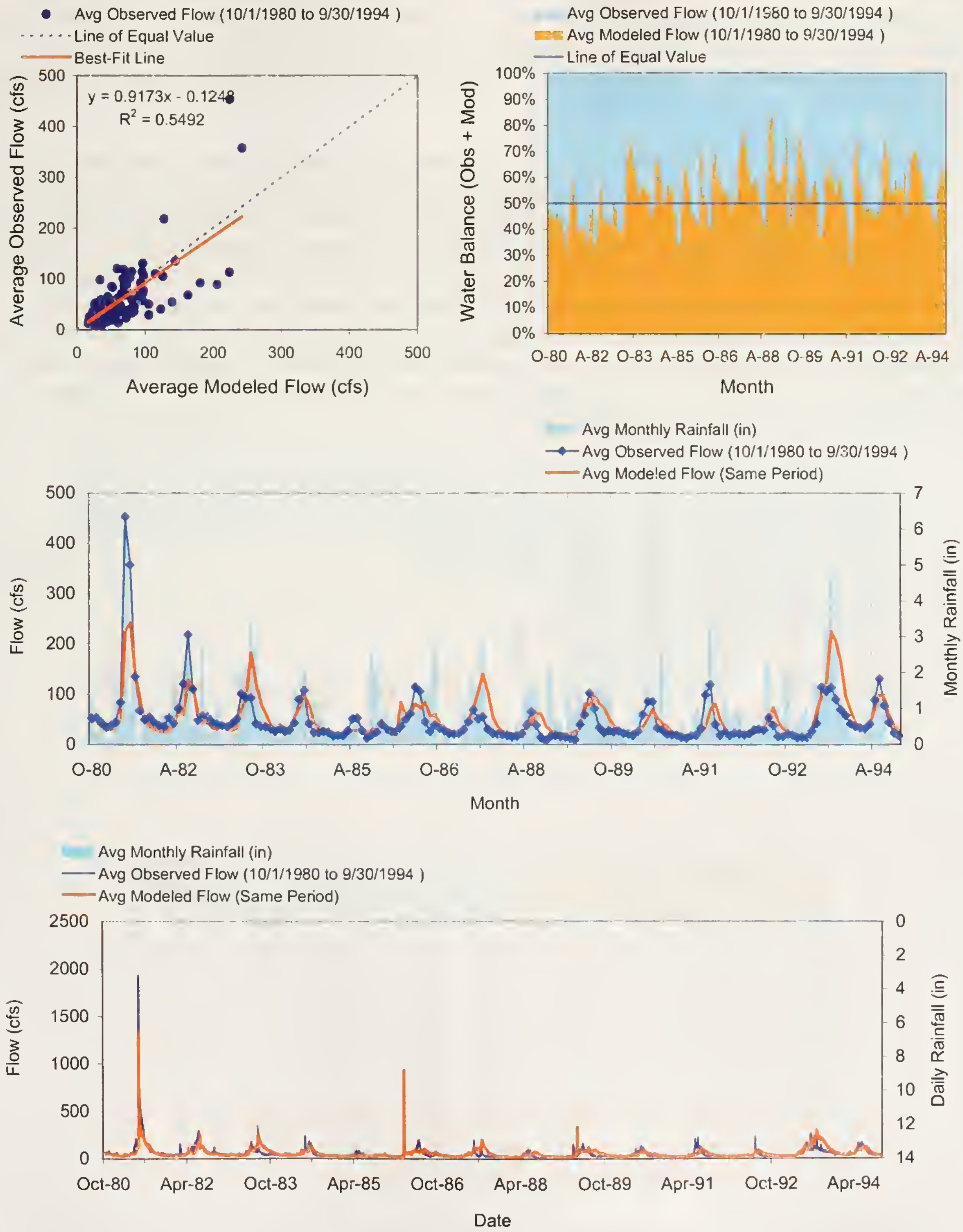
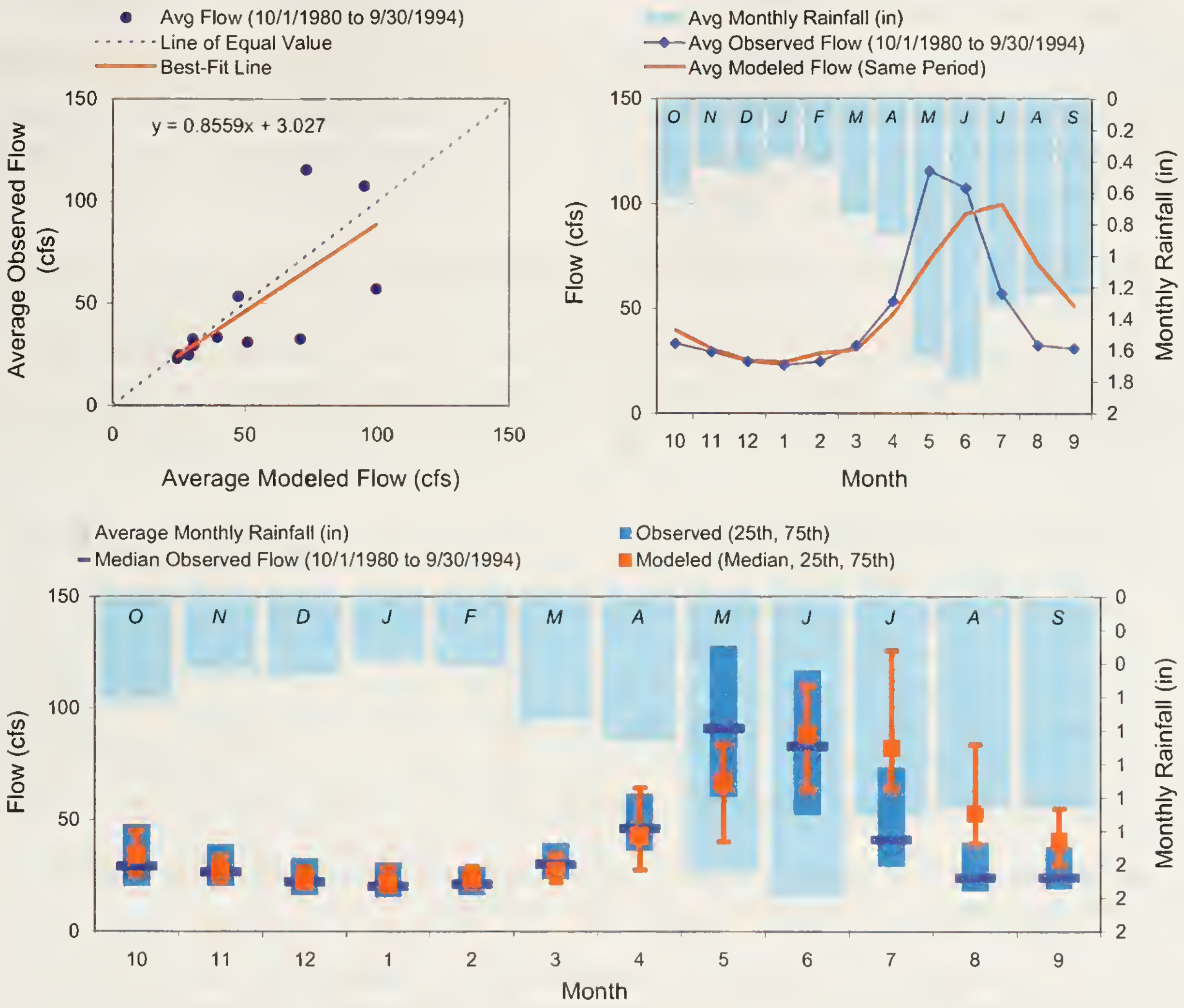


Figure 4-3. Observed versus modeled flows at USGS gage 06061500 – Prickly Pear Creek near Clancy MT.

Figure 4-4 shows the yearly composite calibration analysis for USGS gage 06061500 (Prickly Pear Creek near Clancy, Montana), which represents seasonal hydrologic patterns. All data within the time period is collapsed into a representative-year profile. Average flows, as well as monthly medians, and percentile ranges are used to evaluate the general tendency of the model to represent the observed seasonal variability.

The first plot (upper left) shows the correlation between yearly average observed and modeled flows. Years with less flow (i.e., less snowpack) are most similar, having a strong correlation. As average yearly flows increase, the correlation between simulated and observed average yearly flows decreases. This is mostly because of the errors in the snowmelt simulation, as described in the previous paragraphs. The snowmelt issues are further exemplified in the second plot (upper right). Total yearly flow appears to be similar between the observed and simulated data. The observed data shows that the majority of snowmelt occurs in April, May, and June, while the simulated data suggests that snowmelt occurs primarily in May through August – a longer time period, and later in the year. The third plot (middle center) confirms this analysis. The model is well calibrated from October through April.



MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	33.25	29.00	20.00	48.00	39.47	34.25	25.37	45.00
Nov	29.28	26.50	20.00	39.00	30.70	27.28	22.10	33.13
Dec	24.62	22.00	16.00	33.00	25.20	23.26	19.60	28.38
Jan	22.84	20.00	15.00	31.00	24.40	21.93	18.17	28.84
Feb	24.64	21.00	16.00	29.00	28.69	23.68	19.58	29.01
Mar	32.31	30.00	23.00	39.75	30.30	26.99	21.75	34.34
Apr	53.25	46.00	36.00	62.00	47.36	42.94	27.53	64.42
May	115.38	91.00	60.25	128.00	73.02	66.83	40.15	83.87
Jun	107.31	83.00	52.00	117.25	94.89	88.29	63.31	110.27
Jul	56.92	41.00	29.00	73.75	99.54	82.12	64.24	125.86
Aug	32.37	24.00	18.00	40.00	70.86	52.66	39.14	83.58
Sep	30.83	24.00	19.00	38.00	50.94	40.45	29.78	54.83

Figure 4-4. Composite analysis of observed versus modeled flow at USGS gage 06061500 – Prickly Pear Creek near Clancy MT.

4.1.3.2 Statistical Evaluation

Error statistics for USGS gage 06061500 (Prickly Pear Creek near Clancy, Montana) were calculated and compared to criteria recommended for HSPF. Errors are determined by comparing simulated flow values to observed flow values for various time periods (e.g., for the highest flow periods) using the following equation:

$$\mathrm{Re}\,lativeError = \frac{\mathbf{SimulatedValue} - \mathbf{ObservedValue}}{\mathbf{ObservedValue}} \times 100$$

One goal of the calibration process is to reduce the relative error to less than the recommended criteria for as many flow categories as possible. The following recommended criteria (i.e., accepted level of error between modeled and observed flows) were used:

- Error in total volume: ±10%
- Error in 50% lowest flows: ±10%
- Error in 10% highest flows: ±15%
- Seasonal volume error - Summer: ±30%
- Seasonal volume error - Fall: ±30%
- Seasonal volume error – Winter: ±30%
- Seasonal volume error - Spring: ±30%
- Error in storm volumes: ±20%
- Error in summer storm volumes: ±50%

These error statistics were chosen to insure that the hydrologic calibration was adequate for the entire period evaluated, for all seasons, and for all flow events.

Table 4-2 shows the error statistics for USGS gage 06061500. Modeled flows from 1980 to 1994 were compared to the observed flows during the same time period. The total volume of water was well correlated, with the simulated volume only having 8.57 percent more water than observed. Simulated low flows (50th percentile and lower) were 17.40 percent higher than observed flows. This is expected, as irrigation, diversions, and dams regulate much of the low flow events in the Lake Helena watershed, and there were limited data to properly simulate these conditions. Additional detailed data about diversions and dams would improve this error. During high flow events (highest 10 percent of flows), modeled flows were 5.80 percent lower than observed flows. As shown by the graphs, this is primarily due to the limited weather station coverage, and the resulting storm event errors. This is verified by the storm event statistics. Simulated storm volumes were 89.73 percent less than measured, and summer storm volumes were 59.34 percent less than measured.

Seasonal statistics revealed that the hydrologic calibration was good for the winter and fall (October through March), when base flows and lack of diversions help to insure a well-calibrated model. Summer flows were highly over predicted (45.78 percent more than observed), again because the simulated snowmelt was delayed (see Section 4.1.3.1). For the same reason, the spring error statistic indicated that simulated volumes were less than observed.

Table 4-2. Error statistics for observed versus modeled flows at USGS gage 06061500 – Prickly Pear Creek near Clancy MT.

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 202 14-Year Analysis Period: 10/1/1980 - 9/30/1994 Flow volumes are normalized, with total observed as 100		**USGS 06061500 Prickly Pear Creek near Clancy MT** Jefferson County, Montana Hydrologic Unit Code 10030101 Latitude 46°31'09", Longitude 111°56'45" NAD27 Drainage area 192.00 square miles	
Total Simulated In-stream Flow:	**109.37**	Total Observed In-stream Flow:	**100.00**
Total of simulated highest 10% flows:	**33.34**	Total of Observed highest 10% flows:	**35.28**
Total of Simulated lowest 50% flows:	**26.44**	Total of Observed Lowest 50% flows:	**21.83**
Simulated Summer Flow Volume (months 7-9):	**39.68**	Observed Summer Flow Volume (7-9):	**21.52**
Simulated Fall Flow Volume (months 10-12):	**17.05**	Observed Fall Flow Volume (10-12):	**15.57**
Simulated Winter Flow Volume (months 1-3):	**14.60**	Observed Winter Flow Volume (1-3):	**14.01**
Simulated Spring Flow Volume (months 4-6):	**38.05**	Observed Spring Flow Volume (4-6):	**48.90**
Total Simulated Storm Volume:	**2.47**	Total Observed Storm Volume:	**4.68**
Simulated Summer Storm Volume (7-9):	**0.73**	Observed Summer Storm Volume (7-9):	**1.16**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	8.57	10	
Error in 50% lowest flows:	17.40	10	
Error in 10% highest flows:	-5.80	15	
Seasonal volume error - Summer:	45.78	30	
Seasonal volume error - Fall:	8.66	30	
Seasonal volume error - Winter:	3.99	30	
Seasonal volume error - Spring:	-28.52	30	
Error in storm volumes:	-89.73	20	
Error in summer storm volumes:	-59.34	50	

4.1.3.3 Hydrologic Calibration Summary

Overall, the hydrologic calibration for Prickly Pear Creek (USGS gage 06061500) is adequate for the goals of this project. At a yearly scale, water volume is well calibrated, and well suited for calculating yearly loads. October through March are also well calibrated for flow, and could be used to calculate monthly loads. Months typically associated with high flows resulting from snowmelt are not as well calibrated at the monthly scale. Snowmelt and storm event errors prevent management decisions based on daily or weekly loads. At the yearly scale, the model is appropriate for evaluating the extent and location of pollutant loads and sources. The model is also appropriate for assigning TMDLs (calculated at a yearly scale) to pollutant sources. Additional model uncertainties and uses are discussed in Section 4.3.

4.2 Water Quality Calibration

After hydrology was sufficiently calibrated, water quality calibration was performed. The water quality calibration consisted of running the watershed model, comparing water quality output to available water quality observation data, and adjusting pollutant loading and in-stream water quality parameters within a reasonable range. Figure 4-5 shows the 114 stations that were analyzed during the water quality calibration process. Recent data (1997-2003) were used for the calibration process to insure that current conditions were simulated. Most of the data was collected by USGS, USEPA, and Montana DEQ. In-stream water quality data from other sources was limited to a few segments.

The objective was to best simulate low flow, mean flow, and storm peaks at water quality monitoring stations representative of different regions of the basin (and different land uses, in particular). Modeling parameters were varied within generally accepted bounds and in accordance with observed temporal trends and soil and land cover characteristics. An attempt was made to remain within the guidelines for parameter values set out in BASINS Technical Note 6 (USEPA, 2000).

Graphical results of model performance were evaluated following each water quality simulation. Model parameters were adjusted following iterations to improve model performance. The full set of water quality parameters are included in Section 5.0 and a discussion of the key parameters and how they were adjusted is presented below in Section 4.2.1.

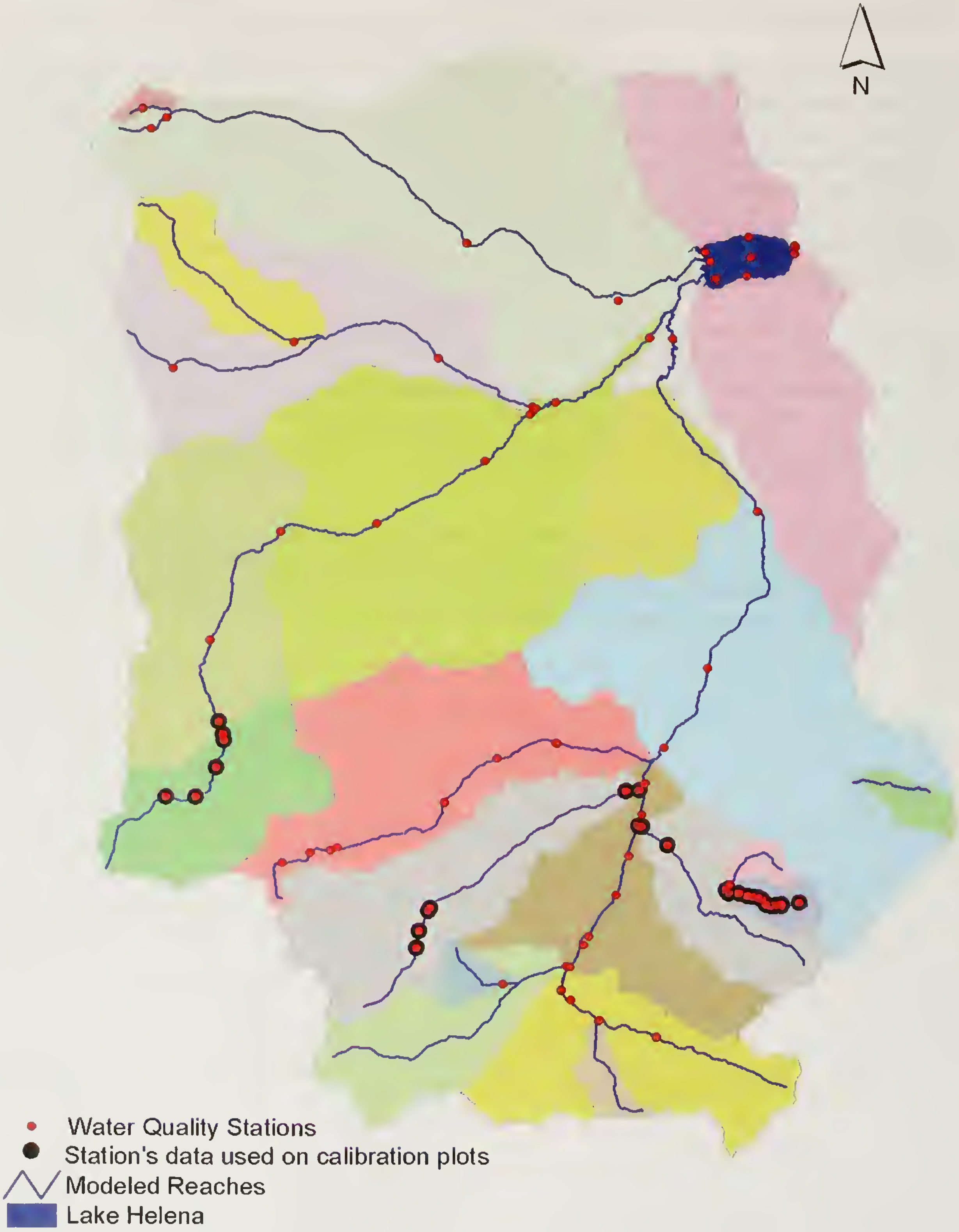


Figure 4-5. Location of water quality monitoring stations in the Lake Helena watershed.

4.2.1 Water Quality Calibration Parameters

In this modeling exercise, the results of the GWLF sediment model (see Appendix C) were replicated with LSPC for the different land use categories modeled. Once the sediment loads were matched, a distribution parameter, K_d, along with the average concentration of each metal in bottom sediments (Table 4-3) were applied as "potency factors" to estimate sediment-related metals loading by land use. All sediment was assumed to have the same concentration of metals.

Table 4-3. Distribution Parameter and Average metals sediment concentration.

Metal	Distribution Parameter, K_d (L/kg)	Average concentration in sediment (ug/g)
Arsenic	1×10^5	28.61
Cadmium	1×10^5	1.61
Copper	3×10^5	200.93
Lead	2×10^5	39.95
Zinc	1×10^5	158.66

Once the link between sediment sources and metals was established, additional pathways of metals loading were modeled from abandoned mine lands. This was done using the GQUAL parameters of the PERLND module of LSPC. The objective was to model additional source loading from the mines that occurs almost constantly (i.e. not-sediment related loads) and would correspond to metals in dissolved form, (e.g. seeps and adit discharges).

LSPC's PERLND module simulates water quality processes that occur on pervious land surfaces. The module simulates the movement of water and constituents in overland flow, interflow, and groundwater flow. Important calibration parameters included the pollutant concentration adjustment associated with interflow (IOQC) and the pollutant concentration adjustment associated with groundwater flow (AOQC). All other land uses were assumed to add metals to the stream channels only through the sediment loading, so the IOQC and AOQC values for all the other land uses were set to zero. During calibration, the parameter values of IOQC and AOQC for abandoned mines were adjusted so that the modeled stream concentrations during baseflow would closely match the observed baseflow concentration of metals in the streams. The parameter that most influenced the calibration was that of AOQC. Finally, permitted mines were modeled with their permitted concentrations at all times.

Table 4-4 presents the average calibrated IOQC and AOQC parameter values for the metals of concern.

Table 4-4. Average IOQC and AOQC Parameter Values for Abandoned Mines.

Metal	IOQC (mg/L)	AOQC (mg/L)
As	7.155	7.526
Cd	0.134	0.183
Cu	1.844	3.286
Pb	1.797	2.838
Zn	19.753	43.948

4.2.2 Evaluation of the Water Quality Calibration

Results of the water quality calibration at selected gages are shown in Figure 4-6 through Figure 4-25 and are discussed below.

Measured metals data (arsenic, cadmium, copper, lead, and zinc) indicate that metals concentrations are relatively constant during base flow events at all stations. Concentrations appear to vary mostly in response to storm events, with summer storm events producing the highest recorded metals concentrations. The calibration plots indicate that metals concentrations during baseflow events were well simulated with the LSPC model.

High metals concentrations appear to be correlated with high flows, and specifically from intense storm events producing overland runoff. The result is a “first flush” of metals with the storm event, producing short but intense concentrations spikes. As described in Section 4.1, it was difficult to model storm events and snowmelt because of the lack of weather gages, particularly at higher elevations. This resulted in a poor hydrologic match during some time periods. However, the total water volume was well correlated at the flow calibration gage in Prickly Pear Creek (8.57 percent error statistic) (see Table 4-2). The result of over and under predicting storm events and snowmelt over a long period of time is that the total volume of water is well calibrated. The same phenomenon appears to be true with the water quality data.

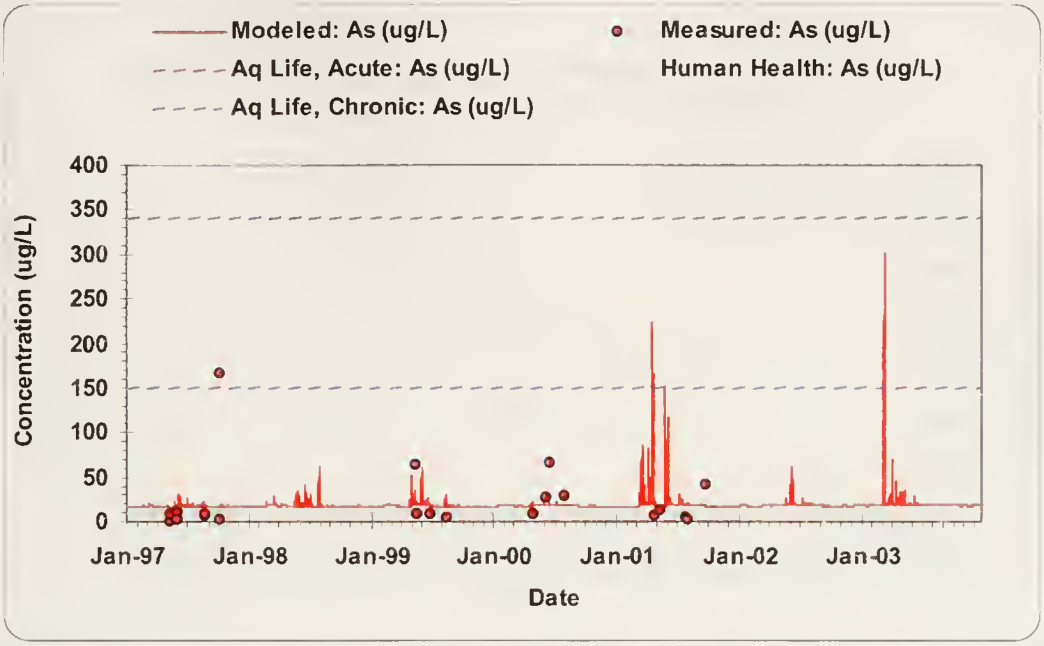


Figure 4-6. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Arsenic.

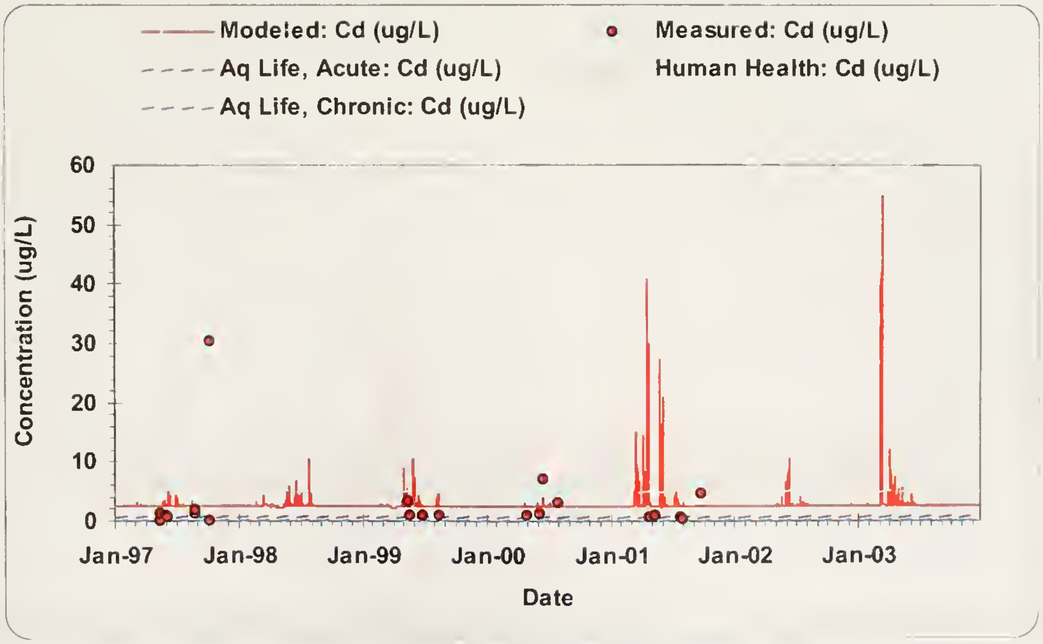


Figure 4-7. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Cadmium.

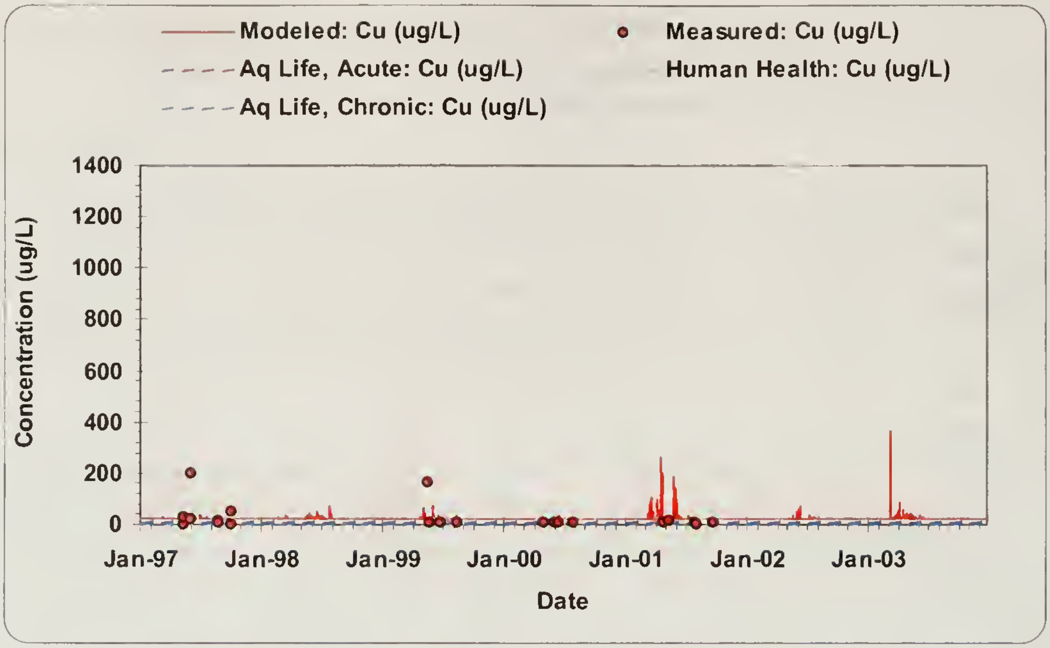


Figure 4-8. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Copper.

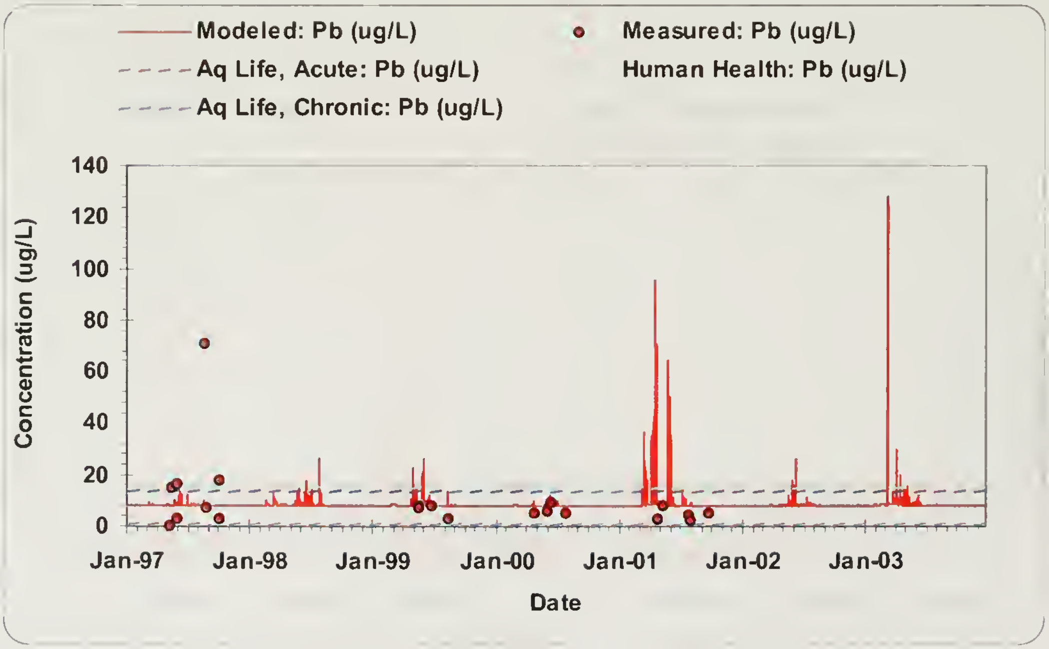


Figure 4-9. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Lead.

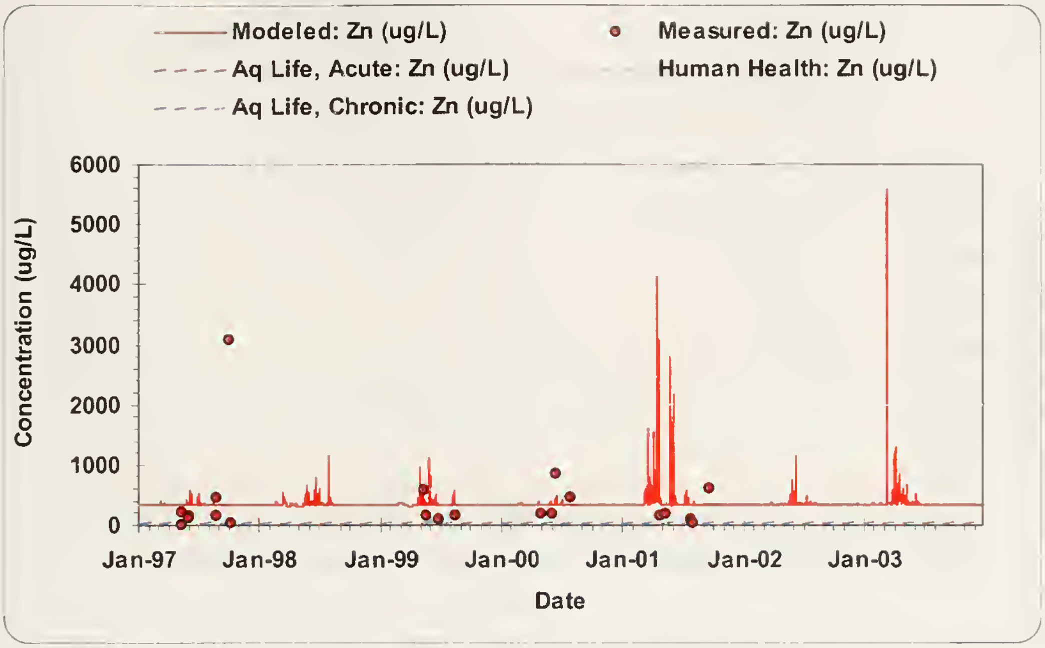


Figure 4-10. WQ Calibration Plots – SWS 501, TENMILE CREEK, headwaters to the Helena PWS intake above Rimini – Zinc.

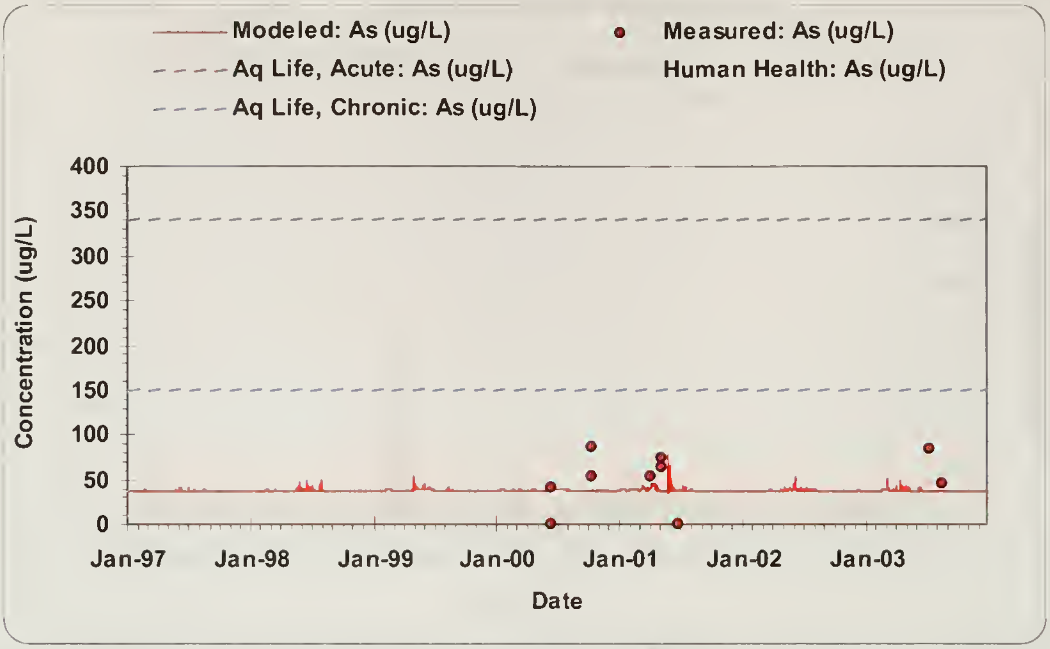


Figure 4-11. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Arsenic.

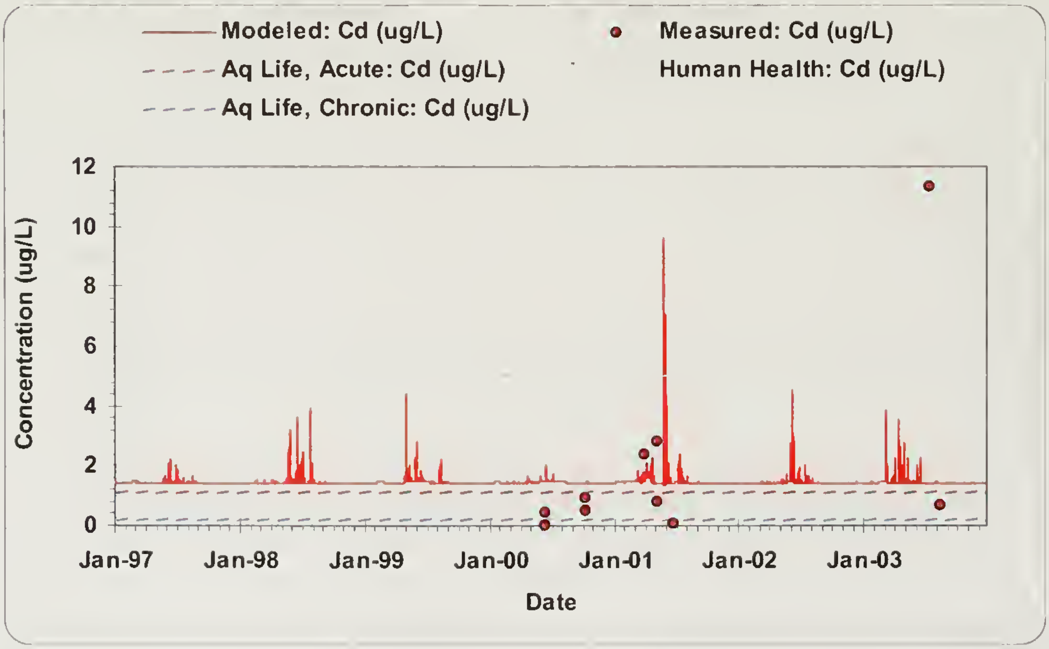


Figure 4-12. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Cadmium.

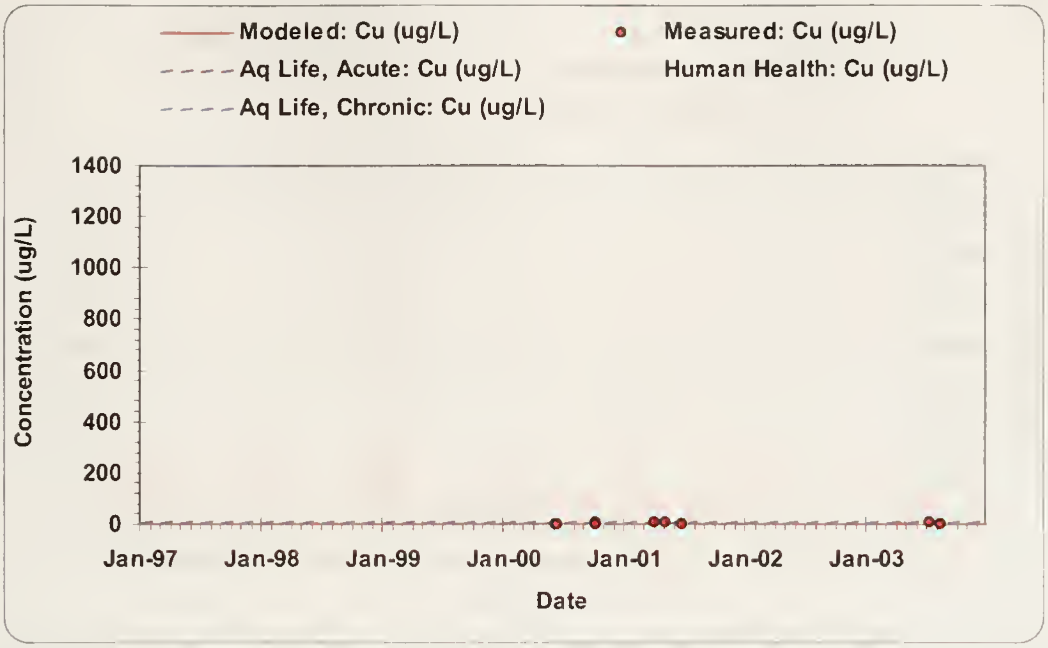


Figure 4-13. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Copper.

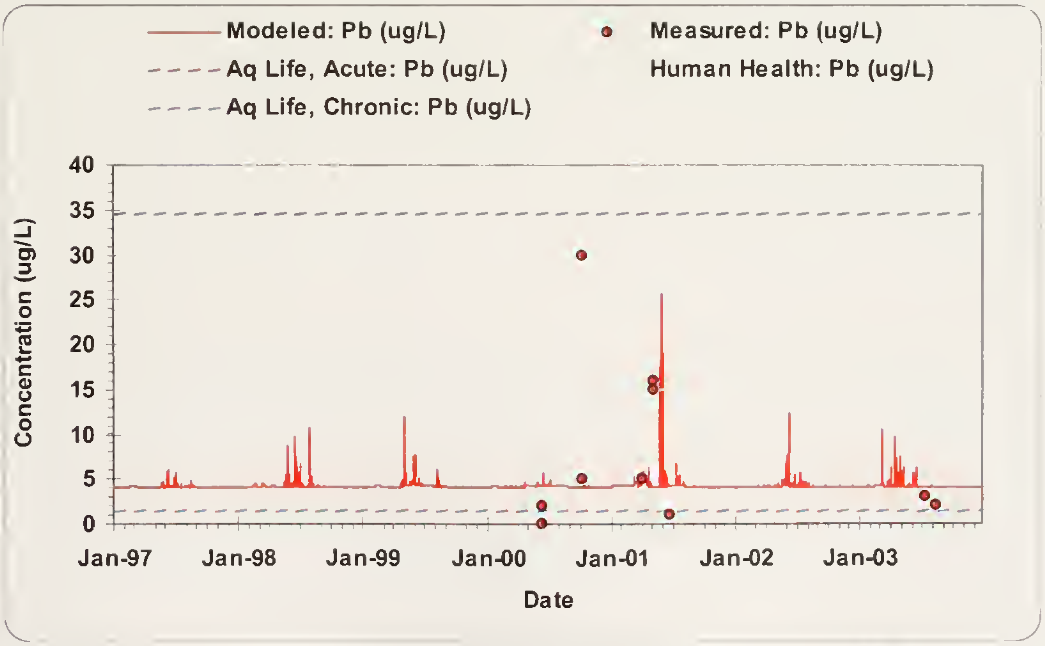


Figure 4-14. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Lead.

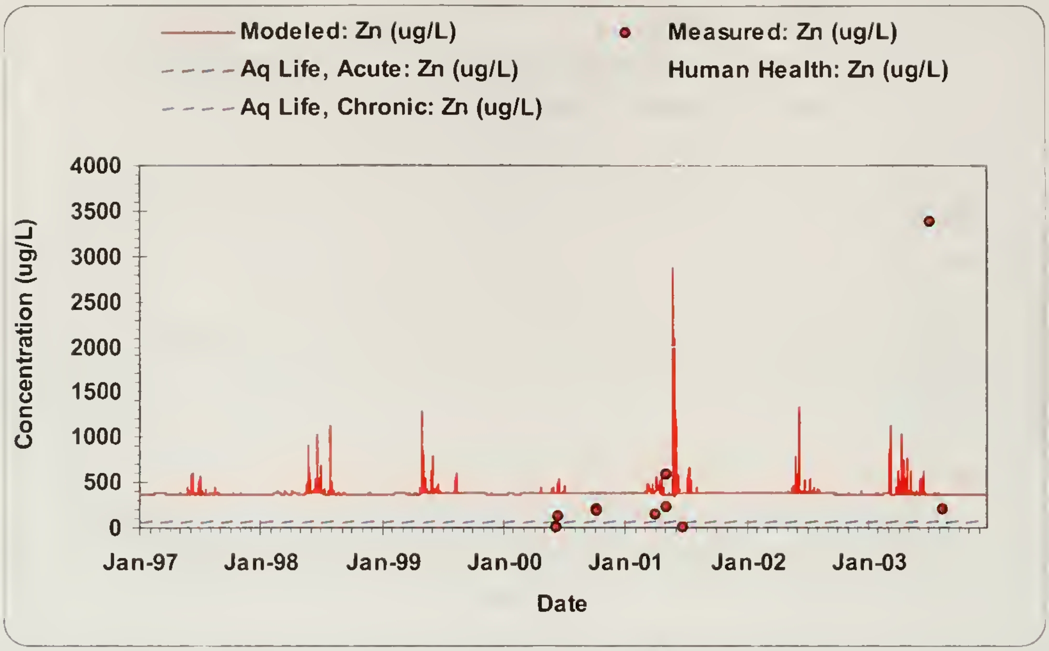


Figure 4-15. WQ Calibration Plots – SWS 304, MIDDLE FK WARM SPRINGS CREEK, Headwaters to mouth (Warm Springs Cr - Prickly Pear Cr) – Zinc.

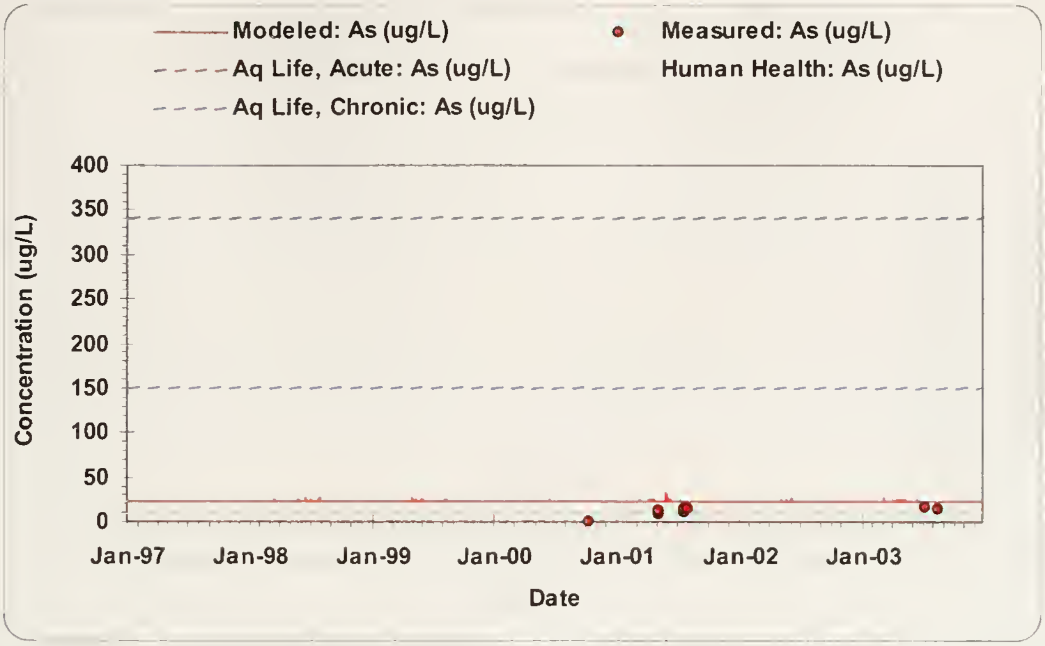


Figure 4-16. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Arsenic.

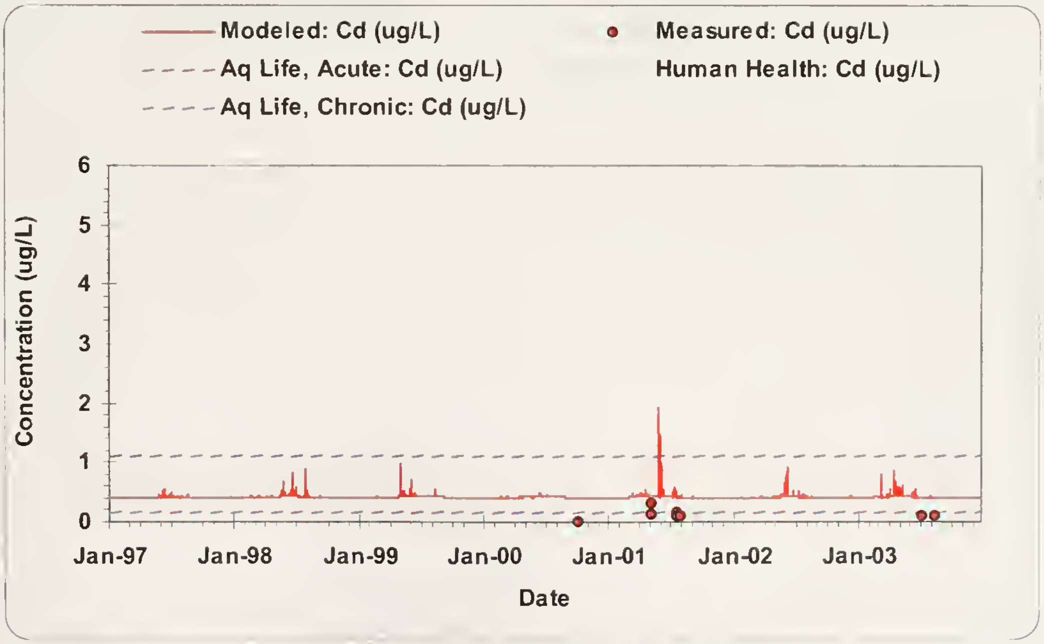


Figure 4-17. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Cadmium.

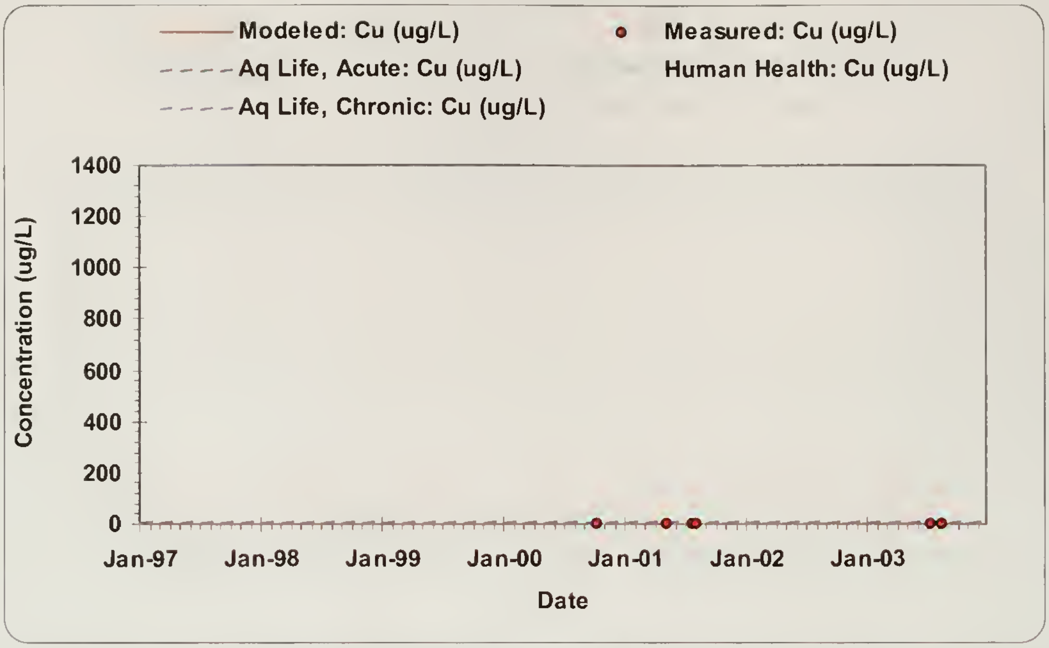


Figure 4-18. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Copper.

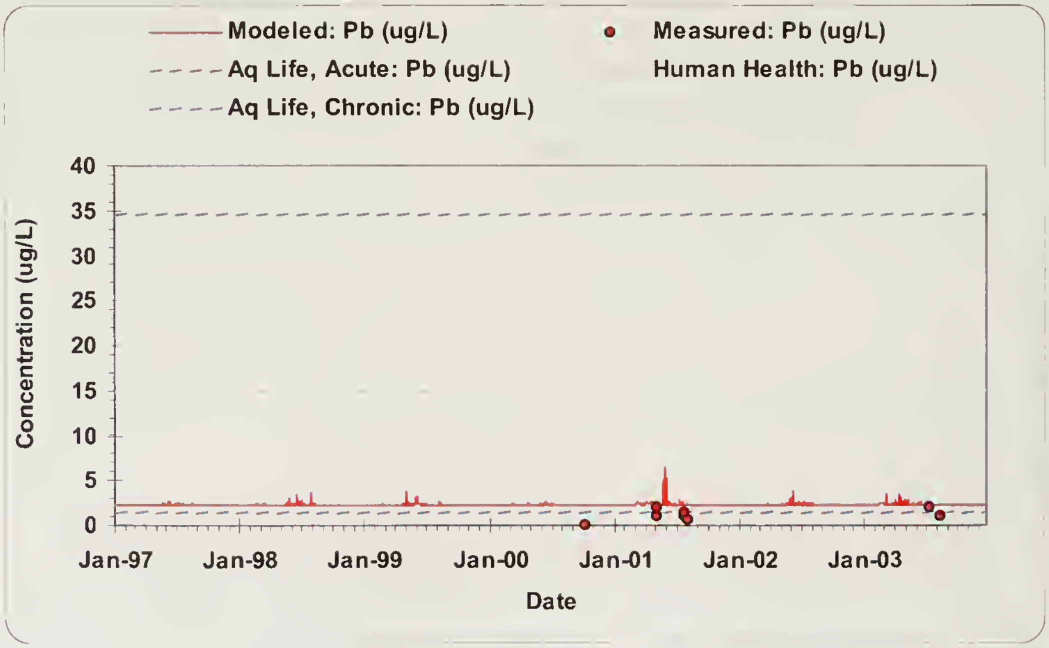


Figure 4-19. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Lead.

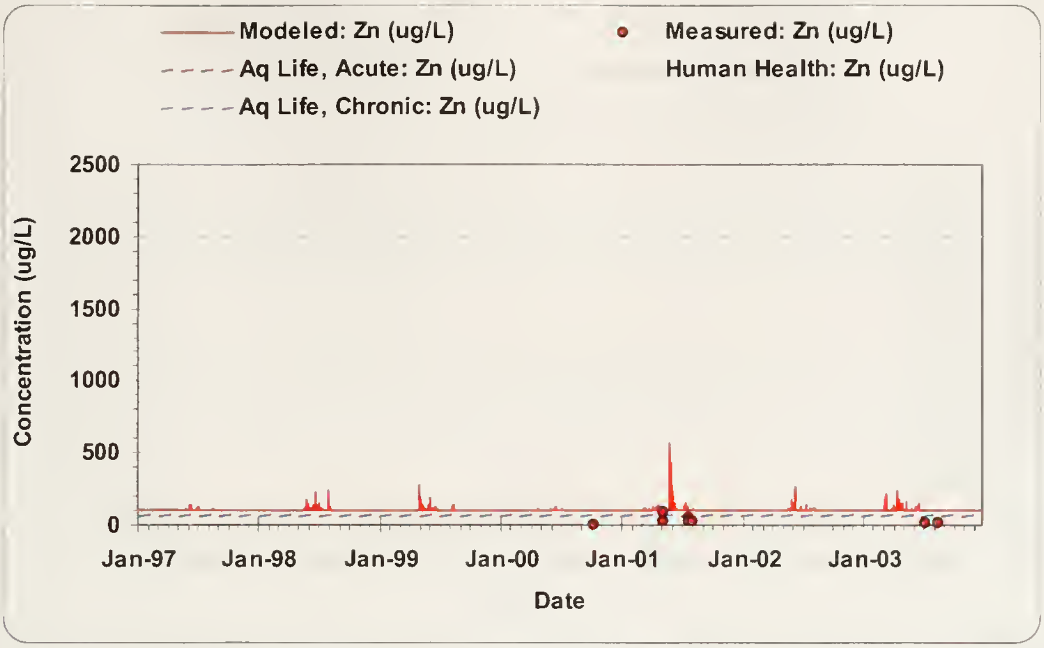


Figure 4-20. WQ Calibration Plots – 303, WARM SPRINGS CREEK from the Middle Fork to the mouth (Prickly Pear Cr) – Zinc.

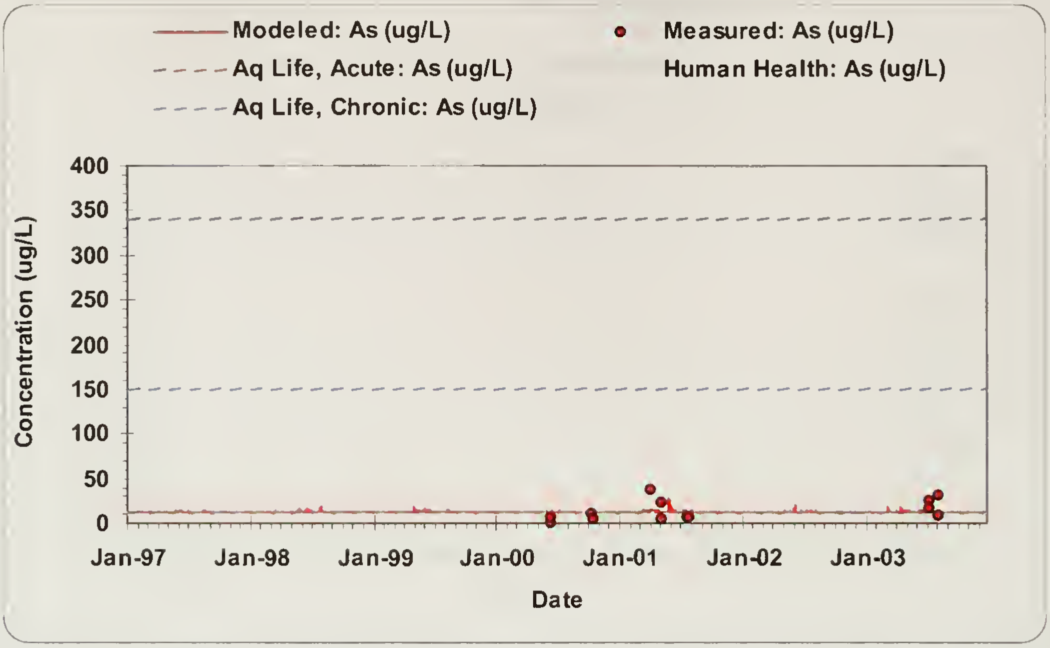


Figure 4-21. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Arsenic.

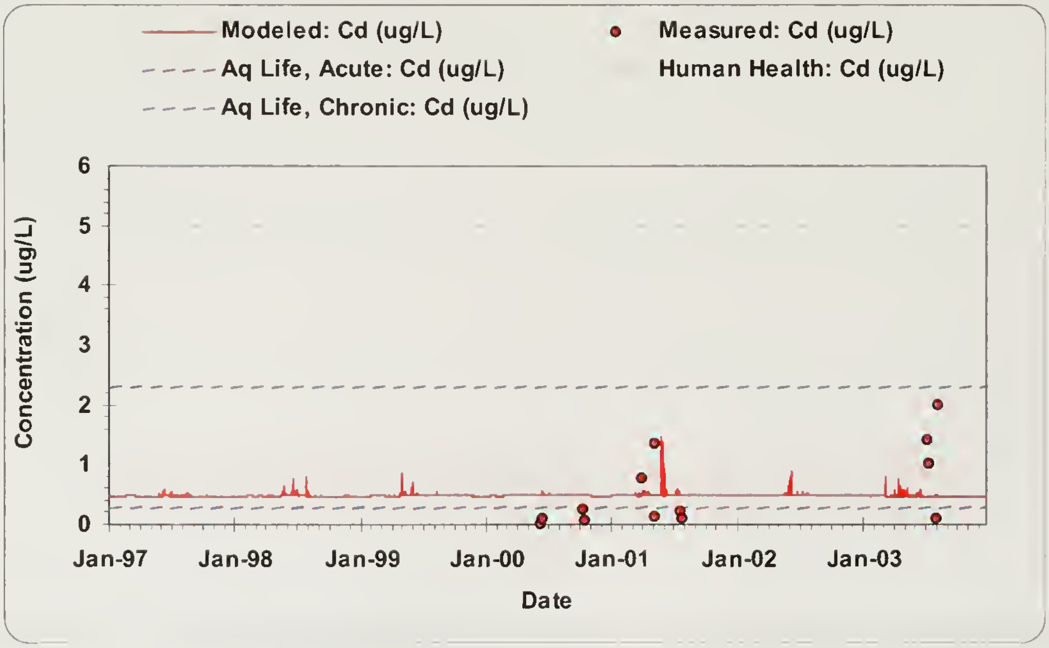


Figure 4-22. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Cadmium.

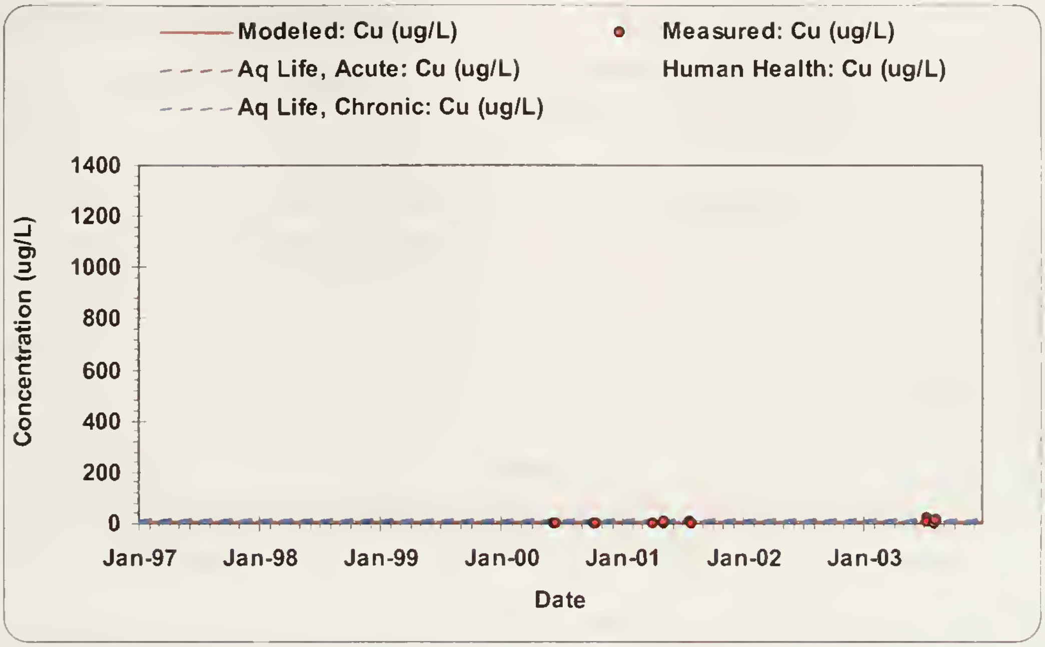


Figure 4-23. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Copper.

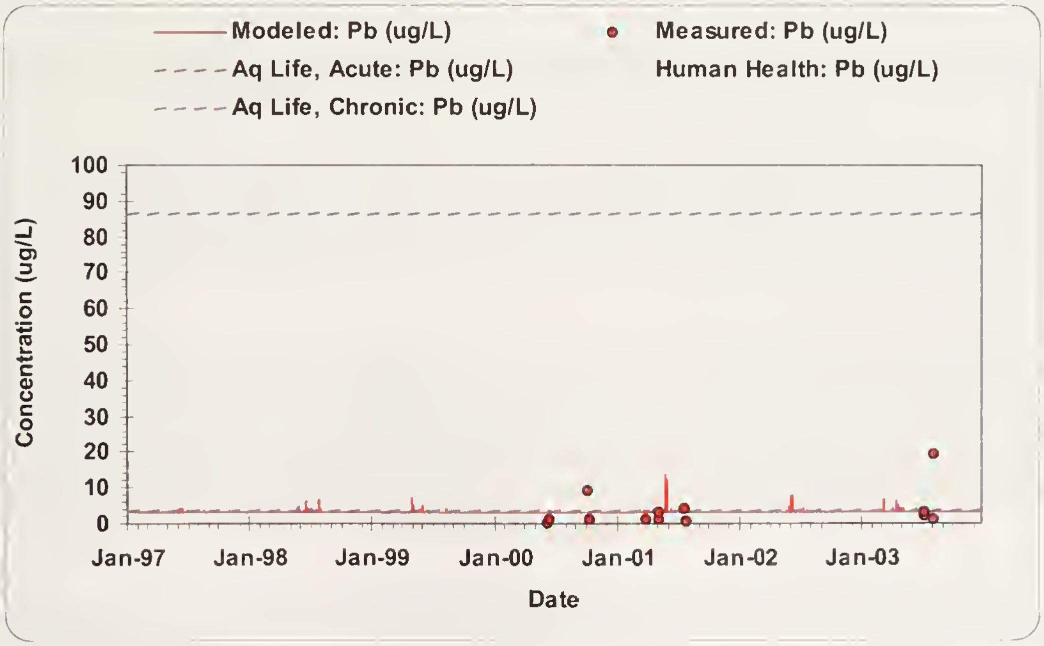


Figure 4-24. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Lead.

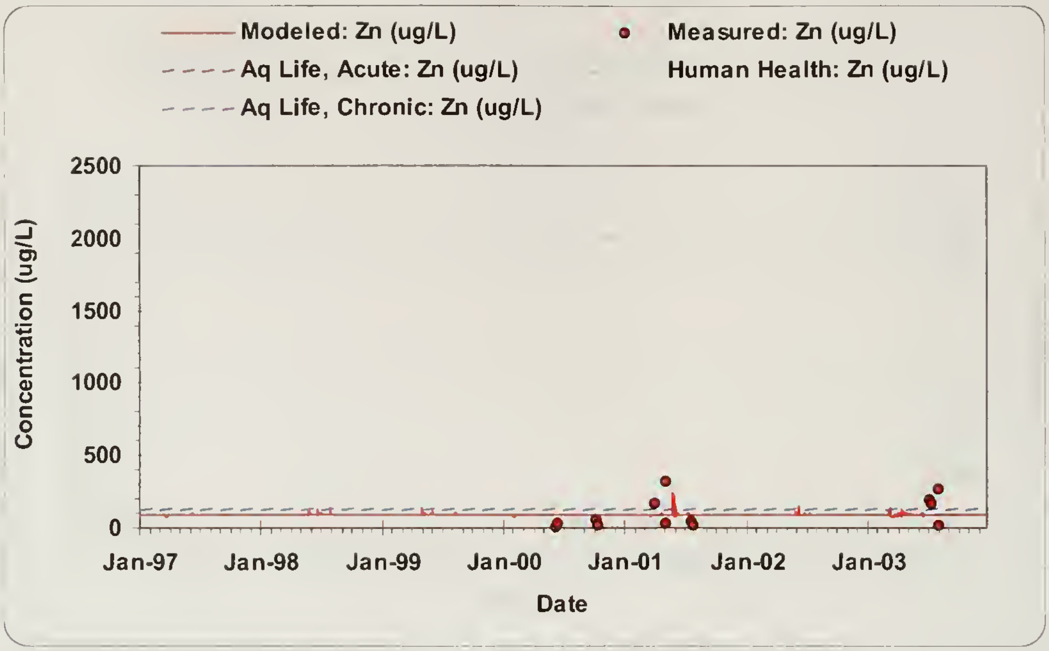


Figure 4-25. WQ Calibration Plots – SWS 302, CLANCY CREEK from headwaters to the mouth (Prickly Pear Cr) – Zinc.

4.3 Model Uncertainty and Use

As described in Section 1.0, modeling was conducted to help answer the following key questions:

- What is the extent to which current flow and in-stream metals concentrations have been affected by anthropogenic activities?
- What are the expected flow and metals conditions during periods for which no observed data are available?
- What are the existing metals loads from each subwatershed?
- What are the existing metals loads from each source category (i.e., point sources, abandoned mines, natural background)?
- What are allowable metals loads from each subwatershed and source category that will result in the attainment of water quality standards?
- What are the potential benefits of various control options?

Based on the calibration results, the model is better suited to answer some of these questions than others. The following first presents an evaluation of the model's ability to address each of the above listed questions, followed by a summary of the potential sources of model error.

4.3.1 Model Limitations and Use

1. What is the extent to which current flow and in-stream metals concentrations have been affected by anthropogenic activities?

In the absence of synoptic monitoring data from each of the potential sources of metals (e.g., various natural sources, mining, agriculture, etc.), modeling provides the only means by which to determine the relative contribution of metals loading from anthropogenic versus natural sources of metals.

All of the potential sources of error described in Section 4.3.2 introduce error into these results. However, when combined with best professional judgement it is felt that the results provide a reasonable approximation of the relative importance of annual metals loading from the various source categories. While the actual calculated loads should be used with caution, the percent load reductions reported in Appendix A, provide a reasonable starting point from which to begin implementing measures to attain water quality standards.

2. What are the expected flow and metals conditions during periods for which no observed data are available?

Based on the calibration results, it appears that the model is capable of producing reasonable results on an annual or long-term basis. However, in the absence of additional calibration data, the results should not be used for smaller time scales (e.g., daily, storm event, or monthly).

3.

What are the existing metals loads from each subwatershed?

Given limited data, hydrologic calibration was based on one site on Prickly Pear Creek (USGS gage 06061500) near Clancy (i.e., in the middle of the Lake Helena Watershed). The total volume of water was well correlated, with the simulated volume only having 8.57 percent more water than observed. On an annual basis, it can be assumed that the results from subwatersheds upstream of the USGS gage on Prickly Pear Creek near Clancy are similar.

In the absence of actual monitoring data, the model results provide the only means to estimate subwatershed scale metals loading. It is felt that the results provide a reasonable first approximation of metals loads from each subwatershed. Additional long-term monitoring would be necessary to verify and/or fine-tune the results.

4. What are the existing metals loads from each source category (i.e., point sources, abandoned mines, natural background)?

See Number 1, above.

5. What are allowable metals loads from each subwatershed and source category that will result in the attainment of water quality standards?

In and of itself, answering this question is straight forward and not subject to its own set of errors. The allowable loads are calculated by multiplying the water quality standard (concentration) by flow to obtain a load. However, the results are subject to the errors associated with the prediction of existing subwatershed and/or source category flows and loads. The model limitations associated with this are described above under Numbers 1 and 3.

In spite of the limitations, this method provides the only means for estimating allowable loads and/or necessary load reductions by subwatershed or source category in the absence of monitoring data.

6. What are the potential benefits of various control options?

The potential benefits of various control options were assessed as a post-processing step. The uncertainties associated with the estimation of load reductions that may be achievable are described in the TMDL tables presented in Appendix A. In general, the estimated achievable load reductions are likely over estimates.

4.3.2 Potential Sources of Model Error

Weather Data

Weather gages are most likely the largest source of model error. The Helena Airport had the only weather gage available for the modeling analysis, and it was responsible to generating precipitation data for 620 square miles. The lack of weather gages significantly increases model error in terms of amount and timing of water flowing through the system. Lack of weather gages particularly increases model error during storm events (timing and volume of water).

Flow Alterations

Flow alterations (diversions, storage, releases) are pervasive throughout the watershed, and can be a source of error in the model. The location of the flow alteration, as well as the volume and timing of flow, is required to accurately model stream flows and water quality. The best available information was used to account for all flow alterations; however, it is acknowledged here that many diversions, ponds, reservoirs, and returns may not be accurately represented in the model. Reservoirs, and reservoir storage, timing, and release, also had limited data. Combined, these uncertainties affect model output in several ways. Primarily, the timing and amount of stream flows may have errors, particularly during the irrigation season (April–September) when diversions and reservoirs are most active. Flow alterations, by nature, have a more pronounced effect on stream flow and water quality during low flows, when a larger percentage of water in the river is diverted. This translates into greater model uncertainties during low flow periods, and particularly during critical low flow summer periods.

Point Source Discharge Data

Point source discharges have the potential to affect flow and water quality in a stream. The LSPC model can account for these sources by using time-series inputs of flow and concentrations. However, most point sources only report data on a monthly basis (or less), and data was extrapolated to provide daily model input. In other cases, very little information was available about the point sources, and best professional judgment was used to estimate flow, timing, water quality, and/or outfall location. Point source uncertainties have the greatest potential to affect model output during low flow events, when point sources make up a larger percentage of the load.

Land Use Data

Each LSPC/HSPF model is driven by the basic physiographic characteristics that make up a watershed – land use, soils, slopes, and geology (see Section 3.2). Therefore, physiographic data must be accurate and complete for each subwatershed. Potential errors were introduced into the model because several of these physiographic characteristics were simplified to facilitate modeling (see Section 3.2). Also, physiographic characteristics change over time, and may or may not be represented by the available data and the chosen calibration period. However, this process most likely does not introduce much modeling error when compared to the other potential sources or error.

Due to the large watershed sizes and model limitations, large areas of land were lumped together as modeling subwatersheds. This process, inherent with all LSPC/HSPF models, potentially creates errors due to the simplification of watershed characteristics. However, this process most likely introduces little modeling error when compared to the other potential sources or error.

Insufficient Hydrology Calibration Data

Hydrology calibration data were one source of model error. Only one flow gage met the LSPC calibration criteria – Prickly Pear Creek near Clancy, Montana. Other gages had too little data, not enough recent data, and/or were located downstream of major flow diversions. Model calibration parameters (such as infiltration, lower zone evaporation, etc.) were calibrated to flows at the Prickly Pear Creek gage, and every subwatershed was then modeled using these parameters. This assumes that surface and subsurface hydrology throughout the entire Lake Helena watershed is similar to that occurring upstream of the Prickly Pear Creek station. However, the Prickly Pear Creek gage is not necessarily representative of hydrology throughout the entire watershed. In particular, this gage does not capture the change in hydrology as streams flow into the Helena Valley. This gage is also not representative of flows in small, high altitude subwatersheds (such as Golconda Creek or Corbin Creek). The result of the lack of flow gages is that varying flow errors are introduced throughout the Lake Helena watershed. The errors are not quantifiable, simply because there are no other flow gages with which to validate the hydrologic calibration. A plan to address this data deficiency is presented in Appendix H.

Insufficient Water Quality Calibration Data

While there were over 100 stations with water quality data in the Lake Helena watershed, most had few recent metals data. Stations with the most data were used to calibrate water quality (see Section 4.2.2). The available data generally consisted of discrete grab samples collected over a period of several years. This type of data provides a poor means for calibrating a model. As a result, there was insufficient data to calibrate to all potential watershed conditions, such as storm events, low flows, high flows, and spring snowmelt. A plan to address this data deficiency is presented in Appendix H.

4.3.3 Model Use

Taking into account the known uncertainties, the model is best used to:

- Calculate and allocate yearly metals loads.
- Run scenarios to evaluate the likely relative impact of various alternative model inputs at the watershed scale.

Due to model uncertainties, the model should not be used to predict the flow and/or concentrations at a specific point in the watershed on a specific day. Rather, the model is best suited for evaluating long-term trends (yearly or greater), or long-term patterns of exceedances.

5.0 LSPC INPUT PARAMETERS

The final LSPC input file contains 255 pages of code and includes all data necessary for running the LSPC model. The most sensitive parameters (such as infiltration or groundwater concentrations) are discussed in Sections 3.0 and 4.0 of this document. An input file and database containing all information used to run the LSPC model is available upon request from the Montana Department of Environmental Quality.

6.0 REFERENCES

Anderson, E.A. and N.H. Crawford. 1964. The synthesis of continuous snowmelt runoff hydrographs on a digital computer. Stanford University Department of Civil Engineering Technical Report 36. 103 p.

Anderson, E.A., 1968, Development and testing of snowpack energy balance equations: Water Resources Research, v. 4, n. 1, p. 19-38.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C. (1997). Hydrological Simulation Program - FORTRAN, User's manual for version 11. Athens: USEPA, EPA/600/R-97/080.

Caruso, Brian S. Simulation of Metals Total Maximum Daily Loads and Remediation in a Mining-Impacted Stream. Journal of Environmental Engineering. ASCE | May 2005 | 1

CDM. 2001. Draft Remedial Investigation Report ,Upper Tenmile Creek Mining Area Superfund Site, Lewis and Clark County, Montana, prepared for EPA.

COE. 1956. Snow hydrology. U.S. Army Corps of Engineers. North Pacific Div. Portland OR.

Crawford, N.H. and R.K. Linsley. Digital Simulation in Hydrology: Stanford Watershed Model IV. Department of Civil Engineering, Stanford University. Tech Report 39. July 1966.

Lumb, A.M., R.B. Mc Cammon, and J.L. Kittle Jr. 1994. Users Manual for an Expert System (HSPEXP) for Calibration of the Hydrologic Simulation Program – Fortran: USGS Water Resources Investigations Report 94-4168, 102 p.

MDEQ (Montana Department of Environmental Quality). 2002. Circular WQB-7 – Montana Numeric Water Quality Standards. Montana Department of Environmental Quality, Planning, Prevention, and Assistance Division Water Quality Standards Section, Helena, MT.

Montana State Library. 1992. Abandoned Mines [Online]. Abandoned mines coverage produced from the Montana Department of Environmental Quality, Abandoned Mines Bureau, Department of State Lands in 1992. Available at http://nris.state.mt.us/gis/ms5.html.

Montana State Library. 1995. Mining Districts of Montana [Online]. Display of mining districts of Montana developed by the Montana Abandoned Mines Reclamation Bureau in 1935 and revised in May of 1995.

Montana State Library. 2002. National Elevation Dataset for Montana. Adapted from the USGS 30-meter digital elevation model (DEM) dataset. Available online at http://nris.state.mt.us/nsdi/nris/el10/dems.html.

Multi- Resolution Land Characteristics (MRLC). 1992. Land use data available for the Multi-Resolution Land Characteristics Consortium. Land use data produced mainly from the 1992 Landsat TM meter coverage (30 m resolution).

Montana State Library. 1997. High Priority Abandoned Hardrock Mine Sites of Montana [Online]. Polygon outlines of abandoned hardrock mine sites inventoried during the Montana Department of Environmental Quality, Mine Waste Cleanup Bureau, Watershed Analysis of Abandoned Hardrock Mine Priority Sites. Available at http://nris.state.mt.us/nsdi/nris/shape/minehipri.zip

Novotny, V., and H. Olem. 1994. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York, NY.

NRCS. 2001. National Soil Survey Handbook [Online]. United States Department of Agriculture. Natural Resources Conservation Service. Available at http://www.statlab.iastate.edu/soils/nssh/.

NRCS. 2004. State Soil Geographic (STATSGO) Database for Montana. Natural Resources Conservation Service, United States Department of Agriculture. Available online at http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/ [Accessed October 11, 2004]..

Rosgen, D., and H.L. Silvey. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

USDA. 1995. State Soil Geographic (STATSGO) Data Base – Data Use Information. U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Miscellaneous Publication Number 1492 [PDF Format]. Fort Worth, Texas.

USEPA. 2000. BASINS Technical Note 6: Estimating Hydrology and Hydraulic Parameters for HSPF. U.S. Environmental Protection Agency, Office of Water Document #EPA-823-R00-012. Available online at http://yosemite.epa.gov/water/owrccatalog.nsf/0/f327b1f5afe8807f85256d08004bed80?OpenDocument

Wischmeier, W.H. and Smith, D.D. 1978. Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. Agricultural Handbook No. 537. U.S. Department of Agriculture, Washington, D.C.

Appendix G

SSTEMP Temperature Modeling

Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report

August 31, 2006

Prepared for the Montana Department of Environmental Quality

Prepared by the U.S. Environmental Protection Agency,
Montana Operations Office
With Technical Support from Tetra Tech, Inc.
and PBS&J, Inc.

Project Manager: Ron Steg

Table of Contents

1.0 Introduction **1**
2.0 Model Setup and Calibration **3**
2.1 Calibration Inputs 3
2.1.1 Flow and Temperature Inputs 6
2.1.1.1 Segment 1a and 1b *6*
2.1.1.2 Segment 2 ..... *6*
2.1.1.3 Segment 3 ..... *7*
2.1.1.4 Segment 4 ..... *7*
2.1.1.5 Segment 5a and 5b *7*
2.1.2 Meteorology Inputs 8
2.1.3 Channel Geometry Inputs 8
2.1.4 Optional Shading Variable Inputs 11
2.1.4.1 Segment 1 ..... *11*
2.1.4.2 Segment 2 ..... *11*
2.1.4.3 Segment 3 ..... *11*
2.1.4.4 Segment 4 ..... *12*
2.1.4.5 Segment 5 ..... *12*
2.2 Calibration Results 13
2.2.1 Segment 1 Calibration Summary 14
2.2.2 Segment 2 Calibration Summary 15
2.2.3 Segment 3 Calibration Summary 15
2.2.4 Segment 4 Calibration Summary 16
2.2.5 Segment 5 Calibration Summary 16
3.0 Model Scenarios **17**
3.1 Comparison to Natural Conditions 17
3.2 Restoration Strategy 21
4.0 References **23**
5.0 SSTEMP Modeling Output **25**

Tables

Table G-1. Temperature impaired segments of Prickly Pear Creek and the corresponding SSTEMP modeling segments. 3
Table G-2. SSTEMP input variables for calibration on August 7, 2003. 4
Table G-3. SSTEMP shading variables for calibration on August 7, 2003. 5
Table G-4. Results of the SSTEMP Calibration. 13
Table G-5. August stream temperatures in Prickly Pear Creek downstream of Clancy Creek (USGS Gage #06061500). 14
Table G-6. August stream temperatures in Prickly Pear Creek upstream of the ASARCO Dam. 15
Table G-7. August 7, 2003 diel stream temperatures in Prickly Pear Creek downstream of the ASARCO Dam. 15
Table G-8. August 7, 2003 diel stream temperatures in Prickly Pear Creek near Sierra Road. 16
Table G-9. SSTEMP input variables for modeled natural conditions. 18
Table G-10. SSTEMP shading variables for modeled natural conditions. 19
Table G-11. Modeled current versus natural daily average stream temperatures in Prickly Pear Creek for a critical summer low flow event. 20
Table G-12. Modeled current average daily stream temperatures in Prickly Pear Creek versus potential TMDL restoration for a critical summer low flow event. 21
Table G-13. SSTEMP input variables for the TMDL restoration strategy for Prickly Pear Creek from Lump Gulch to Wylie Drive. 22
Table G-14. SSTEMP shading variables for the TMDL restoration strategy for Prickly Pear Creek from Lump Gulch to Wylie Drive. 22

Figures

Figure G-1. Segments of Prickly Pear Creek that are temperature impaired. 2
Figure G-2. Width to flow relationship for MT41I006_040 based on data from the USGS gage station below Clancy (06061500). 9
Figure G-3. Width to flow relationship for MT41I006_030 based on data from the sample site at Wylie Drive. 9
Figure G-4. Width to flow relationship for MT41I006_020 based data from the sample site at Sierra Road. 10

1.0 INTRODUCTION

The Lake Helena Volume I report concluded that Prickly Pear Creek from the confluence of Lump Gulch to the mouth is impaired because of thermal modifications (i.e., increased temperature). To better understand the impairment, temperature in Prickly Pear Creek was modeled with the USGS Stream Segment Temperature Model Version 2.0 (SSTEMP) (Bartholow, 2002). SSTEMP is a simplified, steady-state model capable of predicting the change in temperature along a stream reach. The model simulates the various natural heat flux processes found in a stream such as convection, conduction, and long and short wave radiation. Some of the various user inputs to the model are shown below.

- Hydrology: segment inflow, segment outflow, inflow temperature
- Channel Geometry: segment length, upstream and downstream elevation, wetted width and depth, Manning's "n"
- Meteorology: segment latitude, average daily air temperature, relative humidity, wind speed, ground temperature, thermal gradient, possible sun (percentage), percentage of shade, time of the year

The model predicts mean, minimum, and maximum stream temperatures at a specified reach outflow under steady-state conditions. It also assumes that conditions along the reach – such as air temperature, shade, and channel shape – do not change. "The theoretical basis for the model is strongest for the mean daily temperature" (Bartholow, 2002 p.13). Therefore, mean temperature values were given the most consideration.

The goal of the SSTEMP modeling was to create realistic temperature models under current conditions, to evaluate current condition modeling results against naturally occurring temperature, and to ascertain the relative benefits of restoration measures, such as enhancing riparian vegetation along Prickly Pear Creek. The following sections discuss the setup, calibration, and use of the SSTEMP model.

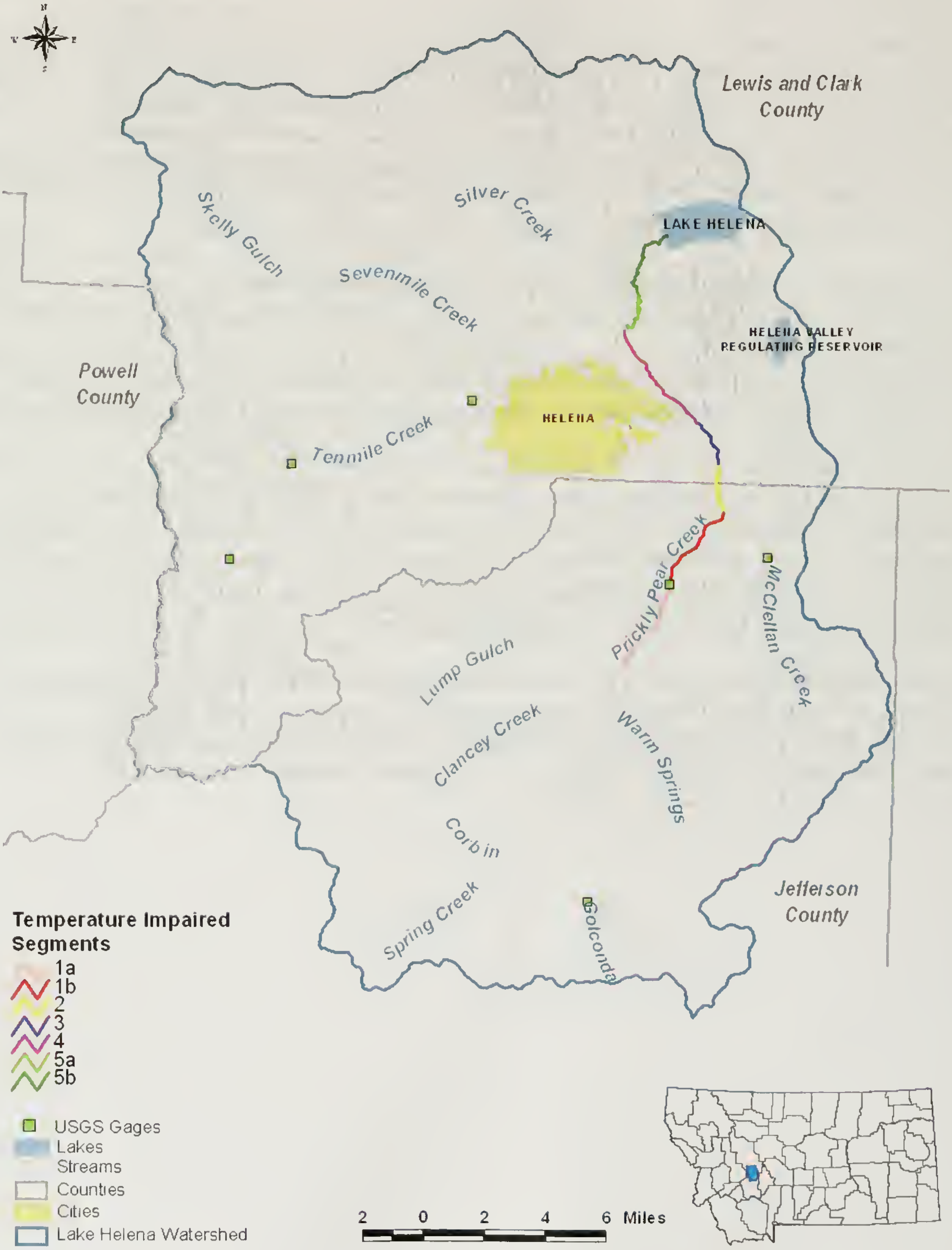


Figure G-1. Segments of Prickly Pear Creek that are temperature impaired.

2.0 MODEL SETUP AND CALIBRATION

SSTEMP is a steady state model, and assumes that stream segments have similar characteristics throughout the modeled reach. However, the impaired portion of Prickly Pear Creek is not homogenous. Characteristics (such as shade, flow, gradient, etc.) vary throughout. Therefore, Prickly Pear Creek was modeled as several smaller segments to account for changes in the reach characteristics. Also, to calibrate the model, segments were delineated to flow and water quality gages. In the end, seven segments were used to calibrate and model temperature in Prickly Pear Creek. (Table G-1; Figure G-1).

Table G-1. Temperature impaired segments of Prickly Pear Creek and the corresponding SSTEMP modeling segments.

303(d) Segment	Modeling Segment	Location
MT41I006_040	Segment 1a	Confluence with Lump Gulch to USGS gage #06061500 (3.5 miles).
	Segment 1b	Confluence with Lump Gulch to confluence with McClellan Creek (6.8 miles).
	Segment 2	Confluence with McClellan Creek to ASARCO Dam (1.7 miles).
	Segment 3	ASARCO Dam to Wylie Drive (1.7 miles).
MT41I006_030	Segment 4	Wylie Drive to Helena Wastewater Treatment Plant discharge (4.3 miles)
MT41I006_020	Segment 5a	Helena Wastewater Treatment Plant to Sierra Road (2.7 miles).
	Segment 5b	Helena Wastewater Treatment Plan to the mouth (5.9 miles).

2.1 Calibration Inputs

After the modeling segments were defined, the model was calibrated to measured conditions in Prickly Pear Creek occurring on August 7, 2003. This date was chosen because there were sufficient calibration data (i.e., segment inflow, segment outflow, air temperature, segment inflow temperature, etc.) collected on or near this date. Also, conditions at that time were representative of critical summer conditions.

SSTEMP input parameters were assigned based on available monitoring data for this date and default parameters suggested in the SSTEMP User's Manual (Bartholow 2002). Input values are shown in Table G-2 and Table G-3. The following sections then describe the rationale for each input value.

Table G-2. SSTEMP input variables for calibration on August 7, 2003.

Input Parameter	Segment 1a	Segment 1b	Segment 2	Segment 3	Segment 4	Segment 5a	Segment 5b
Segment Inflow (cfs)	8.55	8.55	18.9	9.0	3	1.5	1.5
Segment Outflow (cfs)	9.4	9.9	9.0	3.0	1.5	7.5	16.5
Inflow Temperature (ºF)	55	55	64.3	67.2	69.2	59.7	59.7
Accretion Temperature (ºF)	53	53	53	53	53	53	55
Latitude (degrees)	46.51	46.55	46.57	46.59	46.62	46.65	46.66
Dam at Head of Segment	Not checked	Not checked	Not checked	Checked	Not checked	Not checked	Not checked
Segment Length	3.75	7.40	2.28	1.56	5.25	3.03	6.83
Upstream Elevation (ft)	4195	4195	3975	3900	3838	3708	3708
Downstream Elevation (ft)	4067	3975	3900	3838	3708	3677	3650
Width's A Term (s/ft^2)	16.7	16.7	17.0	15.0	14.4	14.8	15.0
B Term	0.098	0.099	0.10	0.11	0.11	0.15	0.19
Manning's n	0.036	0.034	0.032	0.035	0.036	0.035	0.034
Air Temperature (° F)	77.28	77.28	77.81	78.06	78.40	78.74	78.74
Maximum Air Temperature (° F)	Not checked	Not checked	Not checked	Not checked	Not checked	Not checked	Not checked
Relative Humidity (%)	34.0	34.0	33.4	33.2	32.8	32.4	32.4
Wind Speed (mph)	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Ground Temperature (° F)	55	55	55	55	55	55	55
Thermal Gradient (j/m^2/s/C)	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Possible Sun (%)	90	90	90	90	90	90	90
Dust Coefficient	5	5	5	5	5	5	5
Ground Reflectivity (%)	25	25	25	25	25	25	25

Table G-3. SSTEMP shading variables for calibration on August 7, 2003.

Parameter	Segment 1a		Segment 1b		Segment 2		Segment 3		Segment 4		Segment 5a		Segment 5b	
Segment Azimuth (degrees)	45		45		0		-22.5		-45		40		30	
Topographic Altitude (degrees)	West	East	West	East	West	East	West	East	West	East	West	East	West	East
	6	15	12	10	12	6	13	6	6	6	6	4	6	4
Vegetation Height (ft)	10	25	15	25	15	15	10	20	15	10	5	10	5	10
Vegetation Crown (ft)	10	15	10	15	10	15	10	15	10	10	15	10	10	10
Vegetation Offset (ft)	1	1	2	1	3	5	2	4	5	10	5	5	10	5
Vegetation Density (%)	50	55	60	65	40	35	30	50	15	30	20	10	15	25

2.1.1 Flow and Temperature Inputs

Values for inflow, inflow temperature, and segment outflow were obtained from data collected in the field. Data for each modeled segment are summarized below.

2.1.1.1 Segment 1a and 1b

Flow measurements during the summer of 2003 showed that an average of 0.85 cfs was gained between Lump Gulch and the USGS gage station near Clancy, Montana (Segment 1a). Because temperature data were not available for the selected model date at the USGS gage, statistical summaries of the synoptic sampling data from the USGS gage were used to generate a realistic mean temperature for comparison to model results (USGS NWIS 2004). Consideration was given to the effects of drought on the stream's temperature, which resulted in using a higher average output temperature value for model calibration. The value for inflow water temperature was back calculated to achieve the expected average output temperature at the USGS gage. A 53 °F accretion value was used in the model. The accretion value represents one standard deviation above the mean of all USGS synoptic well data for the Lake Helena Watershed from 1980 to 1995 (USGS NWIS 2004). The value was raised by one standard deviation to reflect the effects of drought.

A second model was then run from Lump Gulch to McCellan Creek (Segment 1b) using input from the first model. A total gain of 1.35 cfs of flow was modeled as occurring to account for observed gains at the USGS gage station and an additional 0.5 cfs. Once again a 53 °F accretion value was used in the model.

No significant diversions were identified in the field or from the DNRC water rights database, and streamflow did not appear to be problematic during the summer water quality monitoring or during the field source assessment.

2.1.1.2 Segment 2

Prickly Pear Creek from McClellan Creek to the ASARCO dam (Segment 2) was broken into a separate model due to the large inflow received from McClellan Creek. A flow input of 9 cfs from McClellan Creek to Prickly Pear Creek was modeled. Flow was then withdrawn from the segment because of visible irrigation diversions and records of DNRC identified water rights along the creek. Nine cubic feet per second of flow was withdrawn. Significant irrigation diversions were identified along the lower portion of this segment of Prickly Pear Creek, and were visible on the aerial photographs above the ASARCO holding ponds. Investigation into the DNRC water rights database and communication with the ASARCO environmental manager revealed that the upper holding pond on the creek serves as a reservoir for diverting flow. Segment flow losses were deduced from average summer synoptic streamflow values measured on the creek just downstream of this segment in the summer of 2003. Streamflow was always present in this segment of the creek during the 2003 water quality monitoring and the field source assessment.

The temperature mixing equation was used to arrive at the model inflow temperature by using the mean model output temperature from the upstream segment and a drought elevated temperature value for McClellan Creek (Bartholow 2002). The drought elevated temperature value for McClellan Creek was taken by proportionally raising the mean synoptic July and August temperature observed at the USGS McClellan Creek gage station by 3.95 °F. 3.95 °F represents the increase in temperature observed in the upper-most modeled segment of Prickly Pear Creek for August 7, 2003 over the non-drought mean temperature observed at the USGS gage station. Once again a 53 ° F accretion value was used in the model.

2.1.1.3 Segment 3

Flow input and temperature values were taken from the output model for the upstream segment (outflow from Segment 2) to input into Segment 3 (ASARCO Dam to Wylie Drive). The segment was modeled as loosing 6 cfs. A loss of 6 cfs would equate to an output flow of 3 cfs, which is the flow value observed during the August 7, 2003 diel oxygen and temperature survey. The 6 cfs flow loss also comparable to the flow loss observed during a mid-August 2003 summer water quality monitoring event between the site below the ASARCO dam and the site at Wylie Drive. Once again a 53 ° F accretion value was used in the model. Streamflow was always present in the creek during the 2003 summer water quality monitoring and the field source assessment; however elevated temperatures were noticeable and flows were limited at the end of this segment. A significant irrigation diversion above Wylie Drive was identified during the field source assessment and was also visible on the aerial photographs along this segment of Prickly Pear Creek.

2.1.1.4 Segment 4

For Segment 4 (Wylie Drive to the Helena WWTP outfall), flow and temperature input values were taken from the output model for the upstream segment (outflow from Segment 3). Generally the stream is dry in about one half mile of this 5 mile segment during the summer irrigation season. A significant irrigation diversion was visible on the aerial photographs just downstream of Wylie Drive. Much of the flow gained in the lower portion of this reach is assumed to be groundwater discharge, as water temperatures were noticeably cooler in the lower portion of this segment versus the upper portion of the segment. Flow data measured at the end of segment 4 showed that an average of 1.5 cubic feet per second of inflow was gained near the end of the reach due to groundwater recharge and irrigation returns.

2.1.1.5 Segment 5a and 5b

During the summer, this segment of Prickly Pear Creek is not hydrologically connected by surface water to the upper portion of the creek, due to the dewatering that occurs in the upstream segment. Recent summer flow gains for this segment were calculated from the 2003 synoptic streamflow measurements, and from observations made during the 2003 diel dissolved oxygen and temperature survey. No significant diversions were identified in the field or from the DNRC water rights database, but return flow ditches and a few spring creeks were visible on the aerial photographs. Synoptic sampling data indicate that this segment of Prickly Pear Creek is a flow gaining reach. Streamflow was always present in the creek during the water quality monitoring and the field source assessment; however elevated summer temperatures were noticeable at Sierra Road.

The SSTEMP model was first run on a 3 mile sub-reach of the segment extending from the Helena wastewater treatment plant discharge (WWTP) to Sierra Road (Segment 5a) in order to check model output values against field measured values. A second model was then run for the entire 6.8-mile length of the segment (Segment 5b). Multiple sources of inflow are present within this segment including the City of Helena WWTP, tile drainage and surplus irrigation water discharges associated with the Helena Valley Irrigation District operations, and ground water discharge. Discharges from the WWTP and irrigation drains tend to be highly variable due to seasonal land application of the wastewater and sporadic irrigation water demands. Flow measurements during the summers of 2003 and 2004 showed that an average of 15 cfs was gained between the site above Stansfield Lake (near the beginning of segment MT41I006_020 and just below York Road) and the sampling site at Sierra Road. However, observations on August 7th, 2003 indicated that less than half of this gain was occurring. Therefore model input values for inflows and inflow water temperature were taken from observed flows and measured average temperature at the August 7th, 2003 diel monitoring site above Stansfield Lake. For the second model, a gain of 15 cfs was estimated to occur along the entire segment. To account for warmer inflows from irrigation influenced waters an accretion value of 55° F was used in the model for the entire segment.

2.1.2 Meteorology Inputs

Detailed weather data for August 7th, 2003 were acquired for the Helena Regional Airport from the Weather Underground website (2004). Air temperature and relative humidity values were corrected for elevation differences between the weather station and average values for the stream segments (Bartholow, 2002). The default values were used for ground temperature, thermal gradient, possible sun, dust coefficient, and ground reflectivity values.

2.1.3 Channel Geometry Inputs

Topographic maps and GIS layers were used to calculate elevation, aspect, and stream length for segments MT41I006_040, MT41I006_030 and MT41I006_020. Photo coverage for almost all of the modeled segments was available from 2004 High Resolution Color Orthophotos of the Helena area (1 foot resolution). The level of detail provided by the 2004 Orthophotos lead to an increase in stream segment lengths over the 2004 SSTEMP modeling inputs.

The Width's A and B term represent the wetted width to discharge relationship, where $W = A*Q^B$ (W = known width, A= untransformed y-intercept of the relationship between the natural log of width versus the natural log of discharge, Q = known discharge, and B = power relationship) (Bartholow, 2002). The Width's A and B term were calculated from USGS gage station measurements and from 2003 and 2004 channel cross-sectional measurements taken during the summer sampling events (Figure G-2 to Figure G-4); Wayne Berkas, personal communication). Because the relationship tends to break down at low flow levels, only two of three flow measurement runs were used for Prickly Pear Creek at Wylie Drive (one high and one low flow). Manning's n was selected based on the stream segments' geomorphic characteristics (Barnes 1967, Rosgen 1994).

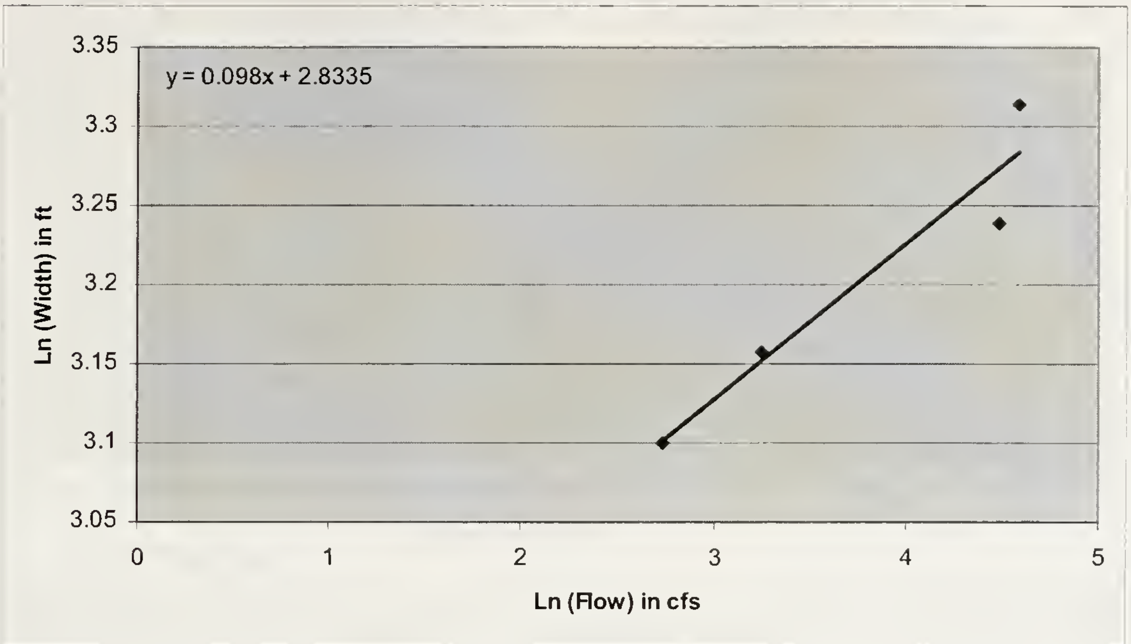


Figure G-2. Width to flow relationship for MT41I006_040 based on data from the USGS gage station below Clancy (06061500).

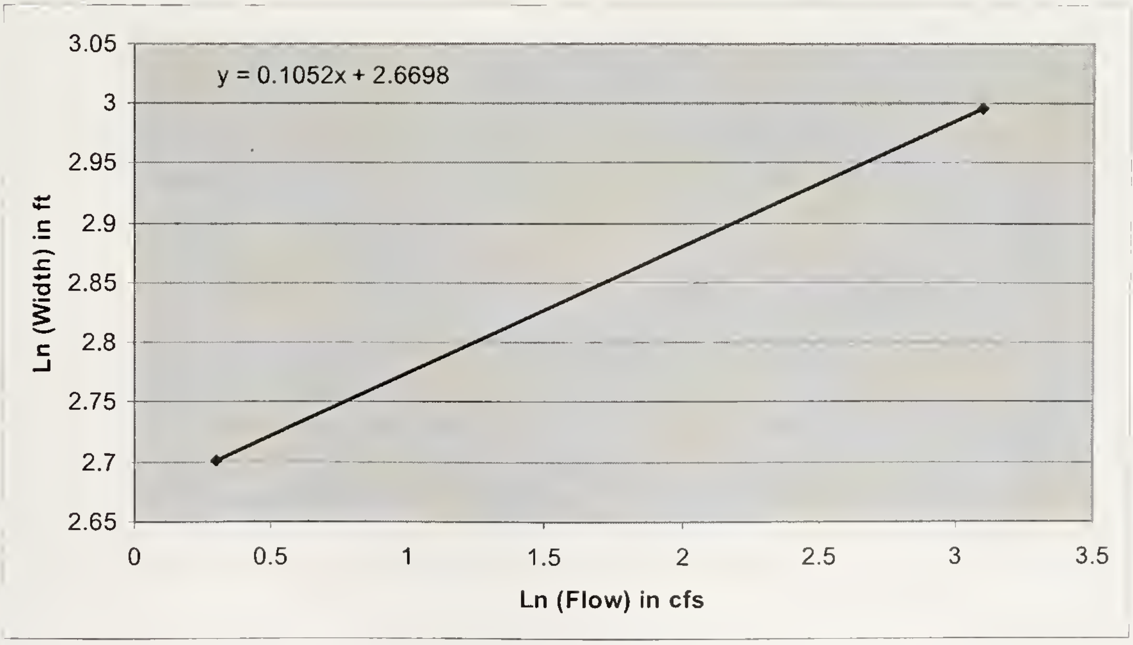


Figure G-3. Width to flow relationship for MT41I006_030 based on data from the sample site at Wylie Drive.

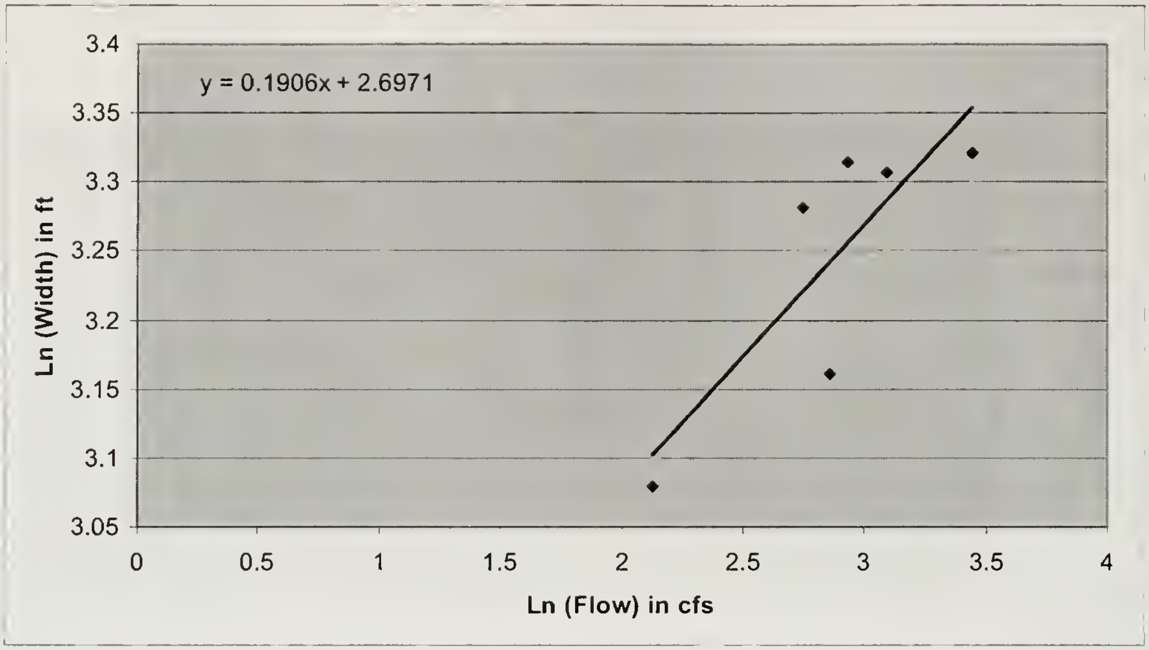


Figure G-4. Width to flow relationship for MT41I006_020 based data from the sample site at Sierra Road.

2.1.4 Optional Shading Variable Inputs

Shading variables were calculated based on site-specific field data collected during the 2005 field source assessment. Point specific field data were adjusted to account for the average, modeled segment reach characteristics. Adjustments were made based on field observations and evaluation of the 2004 High Resolution Color Orthophotos. The following sections describe the riparian condition present along each modeled reach of Prickly Pear Creek.

2.1.4.1 Segment 1

Along this segment of Prickly Pear Creek, riparian vegetation density is variable, but overall fairly dense and in good condition. The dominant riparian vegetation consists primarily of willows with areas of cottonwood overstory. The width of the riparian buffer generally corresponds with the distance from roads, as much of this segment is channelized. However, enough time has passed since road building that the riparian community has recovered to what is generally full potential along the banks of this reach.

2.1.4.2 Segment 2

Along this segment of Prickly Pear Creek, riparian vegetation density is variable, with conditions progressing from good to poor. The dominant riparian vegetation consists primarily of willows with areas of cottonwood overstory. In the upper portion of the segment the width of the riparian buffer is limited by confining valley conditions as well as railway and highway encroachment. A Proper Functioning Condition (PFC) Assessment was conducted near the beginning of this segment in 2003. The field crew rated this site as "Functional – at risk" (FAR). A key reason for the FAR rating was the presence of vigorous riparian vegetation. A significant loss of riparian vegetation occurs from the confluence with Holmes Gulch to the end of this segment and is attributed to extensive channel alterations associated with historic placer mining, current agricultural operations (irrigation diversions, cropping and possibly grazing), and the ASARCO facility.

2.1.4.3 Segment 3

Along this segment of Prickly Pear Creek, riparian vegetation density is variable, but overall fairly dense and in good condition. The dominant riparian vegetation consists primarily of willows with cottonwoods becoming more prominent near the town of East Helena. For most of the segment, the width of the riparian buffer is limited by development adjacent to the stream for the ASARCO facility and the town of East Helena. However, enough time has passed since development that the riparian community has recovered to what is almost full potential along the banks of this reach, save for a section along the ASARCO slag pile.

2.1.4.4 Segment 4

Along this segment of Prickly Pear Creek riparian vegetation density is sparse, and is overall in poor condition. Where present, the dominant riparian vegetation consists of decadent cottonwoods with willow understory. Grasses are more prevalent than woody vegetation species. Loss of riparian vegetation occurs from channel alterations associated with current agricultural practices (irrigation diversions, cropping, and grazing), housing development, and the Helena Sand and Gravel Pit operation. Two Proper Functioning Condition (PFC) assessments were conducted along this segment in 2003. At both sites, the field team gave the stream a rating of "non-functional" (NF). A limited riparian zone and lack of diverse riparian vegetation were some of the reasons for the NF ratings. At the time of the survey, succulent vegetation was growing in the dewatered portion of this segment. There are upstream portions of this segment that have experienced a near total removal of riparian vegetation, but riparian conditions improve slightly near the end of the segment.

2.1.4.5 Segment 5

Along this segment of Prickly Pear Creek riparian vegetation density is sparse, and is overall in poor condition. Where present, the dominant riparian vegetation consists of decadent cottonwoods with willow understory. In many areas, grasses are more prevalent than woody vegetation species. Loss of riparian vegetation occurs from channel alterations associated with housing development and current agricultural practices: cropping and grazing. A Proper Functioning Condition (PFC) assessment was conducted along this segment in 2003, near Sierra Road. The field crew rated this site as "non-functional" (NF), noting a lack of diverse or stabilizing riparian vegetation as some of the reasons for the NF rating. Riparian conditions tend to improve somewhat near the end of the segment.

2.2 Calibration Results

Summary results of the SSTEMP calibration for August 7, 2003 (critical low flow condition) are presented in Table G-4. The difference between measured and calibrated values varied for each segment, and ranged from –6.1 to 6.7 ° F (0 to 10 percent difference). Results of the individual segment calibrations are further discussed below.

Table G-4. Results of the SSTEMP Calibration.

Segment	Parameter	Calibrated Water Temperature	Difference from Measured Water Temperature	Percent Difference
1a – Confluence with Lump Gulch to USGS gage #06061500	Mean	64.0 ° F	+0.4 ° F	1
	Maximum	72.6° F	-4.4 ° F	6
	Minimum	55.3 ° F	+1.7 ° F	3
1b – Confluence with Lump Gulch to confluence with McClellan Creek	Mean	65.7 ° F	+2.1 ° F	3
	Maximum	72.6 ° F	-4.4 ° F	6
	Minimum	58.8 ° F	+5.2 ° F	9
2 – Confluence with McClellan Creek to ASARCO Dam	Mean	67.2 ° F	+0.7 ° F	1
	Maximum	77.4 ° F	+6.7 ° F	9
	Minimum	57.0 ° F	-5.8 ° F	10
3 – ASARCO Dam to Wylie Drive	Mean	69.2 ° F	+0.4 ° F	1
	Maximum	74.3 ° F	-0.7 ° F	1
	Minimum	64.1 ° F	+0.7° F	1
4 – Wylie Drive to Helena Wastewater Treatment Plant discharge[1]	Mean	NA	NA	NA
	Maximum	NA	NA	NA
	Minimum	NA	NA	NA
5a – Helena Wastewater Treatment Plant to Sierra Road	Mean	65.0 ° F	0.0 ° F	0
	Maximum	78.4 ° F	+3.4 ° F	5
	Minimum	55.4 ° F	-6.1 ° F	10
5b – Helena Wastewater Treatment Plan to the mouth	Mean	66.3 ° F	+1.3° F	2
	Maximum	76.0 ° F	+2.3 ° F	3
	Minimum	56.6 ° F	-2.4 ° F	4

[1] Input and output flows in Segment 4 are not hydrologically connected due to dewatering. The segment could not be properly calibrated.

2.2.1 Segment 1 Calibration Summary

The calibration model output for Segment 1a (confluence with Lump Gulch to USGS gage 06061500) was compared to July and August synoptic data collected at the USGS gage on Prickly Pear Creek near Clancy Creek (Table G-5). The calibration model produced mean temperature results within 1 percent of the average synoptic value measured during the drought years of 2000 to 2002 in July and August. The modeled mean value of 64.0° F is 0.4 ° F more than the average synoptic value. This is a reasonable outcome given that the measured temperatures were recorded synoptically, and that the effect of a prolonged drought appears to have naturally elevated water temperatures.

The calibration model for Segment 1b (Lump Gulch to McClellan Creek) produced mean temperature results within 3 percent of the average synoptic value measured during the drought years of 2000 to 2002 in July and August. The modeled mean value of 65.7° F is 2.1 ° F more than the average synoptic value. This is a reasonable outcome given that the measured temperatures were recorded near the middle of the segment, and that little flow is gained in this reach between the USGS gage station and McClellan Creek.

Table G-5. August stream temperatures in Prickly Pear Creek downstream of Clancy Creek (USGS Gage #06061500).

Statistics	August Values (1983-1999)	August Drought Values (2000-2002)
Mean	60.0 ° F	63.6 ° F
Median	58.1 ° F	63.1 ° F
Standard Deviation	6.0 ° F	8.3 ° F
Minimum	50.0 ° F	53.6 ° F
Maximum	69.8 ° F	77.0° F
Samples	15	10

2.2.2 Segment 2 Calibration Summary

The calibration model output for Segment 2 (McClellan Creek to the ASARCO Dam) was compared to August synoptic data collected for the EPA Superfund program upstream of the ASARCO dam (Table G-6). The calibration model produced mean temperature results within 1 percent of the average August synoptic value measured for the EPA Superfund program above the ASARCO dam. The modeled mean value of 67.2° F is 0.7° F more than the average synoptic value. This is a reasonable outcome given that the measured temperatures were recorded synoptically, and that the effect of a prolonged drought appears to have naturally elevated water temperatures.

Table G-6. August stream temperatures in Prickly Pear Creek upstream of the ASARCO Dam.

Statistics	August 1994 and 1995
Mean	66.5 ° F
Median	66.2 ° F
Standard Deviation	2.7 ° F
Minimum	62.8 ° F
Maximum	70.7 ° F
Samples	9

2.2.3 Segment 3 Calibration Summary

The calibration model output for Segment 3 (ASARCO Dam to Wylie Drive) was compared to thermograph data collected on August 7th, 2003 below the ASARCO dam (Table G-7). The calibration model produced mean temperature results within 1 percent of the average value collected by a thermograph on August 7th, 2003 below the ASARCO dam. The modeled mean value of 69.2° F is 0.4° F more than the average thermograph value. This is a reasonable outcome given that the measured temperatures were recorded near the beginning of the segment, before any major flow losses occur.

Table G-7. August 7, 2003 diel stream temperatures in Prickly Pear Creek downstream of the ASARCO Dam.

Statistics	August 7, 2003 Values
Mean	68.8 ° F
Median	68.1 ° F
Standard Deviation	3.9 ° F
Minimum	63.4 ° F
Maximum	75.0° F
Samples	51

2.2.4 Segment 4 Calibration Summary

Segment 4 of Prickly Pear Creek could not be calibrated because of flow alterations near the Wylie Drive Bridge. Flows and temperatures measured at the end of Segment 4 (near the Helena WWTP outfall) represented groundwater recharge and irrigation returns, and not upstream flow.

2.2.5 Segment 5 Calibration Summary

The calibration model output for Segment 5a (treatment plant outfall to Sierra Road) was compared to diel temperature data collected at Sierra Road (Table G-8). The calibration model produced mean temperature results equivalent to the average value measured during the August 7th diel survey. The modeled mean value of 65.0° F is equal to the average survey value.

The calibration model for Segment 5b (treatment plant outfall to Lake Helena) produced mean temperature results within 2 percent of the average value measured during the August 7th diel survey. The modeled value of 66.3° F is 1.3 ° F more than the average survey value. This is a reasonable outcome given that the measured temperature was recorded midway along the segment before more than half of the inflow from groundwater or irrigation returns was gained.

Table G-8. August 7, 2003 diel stream temperatures in Prickly Pear Creek near Sierra Road.

Statistics	August 7, 2003 Stream Temperatures
Mean	65.0 ° F
Median	63.9 ° F
Standard Deviation	5.5 ° F
Minimum	59.0 ° F
Maximum	73.8 ° F
Samples	13

3.0 MODEL SCENARIOS

Once calibrated, the SSTEMP model was used to model natural conditions in Prickly Pear Creek (i.e., no anthropogenic sources), and compare the modeled natural conditions to the modeled existing conditions. Also, SSTEMP was used to assess various restoration strategies (i.e., increased shading, increased flows) to determine how to best remediate the temperature impairments. The following sections summarize the results of the two modeling scenarios – natural conditions and restoration strategies. Complete model output, including a sensitivity analysis, is included in Section 5.0.

3.1 Comparison to Natural Conditions

Current conditions were modeled in Prickly Pear Creek using the input data discussed in Section 2.1. This represents a critical summer, low flow period that is likely to have the most impact from anthropogenic sources. Natural conditions were approximated based on field surveys of flow and habitat alterations, point source data, and best professional judgment. The natural model flow input values, which assumed no flow loss from the major diversions, are within the aquatic life survival flows suggested by MFWP for Prickly Pear Creek (MFWP 1989). In all likelihood, these "natural" flow values represent a conservative estimate of in-stream flows, as the available flow data are not adequate to determine exact flow losses attributed to irrigation diversions or flow gains attributed to groundwater discharge. A water budget study for Prickly Pear Creek is proposed for the TMDL effectiveness monitoring which could be used to identify if in-stream flows could be increased by irrigation water management without affecting water rights (see Appendix H). In order to estimate natural riparian vegetation conditions along lower Prickly Pear Creek, the riparian vegetation was augmented using best professional judgment for most of lower Prickly Pear Creek with consideration given to the full potential of the predominant types of woody vegetation observed in the field. A summary of the natural conditions in each segment is provided below. The naturally occurring values used for each segment are shown in Table G-9 and G-10.

- *Segment 1 (Lump Gulch to McClellan Creek)* – The field survey suggested that Prickly Pear Creek from Lump Gulch to McClellan Creek (Segment 1) was already in a natural condition, and did not require any adjustments to the model input parameters.
- *Segment 2 (McClellan Creek to the ASARCO Dam)* – To achieve natural conditions in Segment 2, flow losses were restored, and riparian density was enhanced along the entire reach.
- *Segment 3 (ASARCO Dam to Wylie Drive)* – Natural conditions in Segment 3 were approximated by using the "natural" flow and temperature outputs from Segment 2, and by augmenting riparian vegetation along the entire reach.
- *Segment 4 (Wylie Drive to the Helena WWTP Outfall)* – Natural conditions in Segment 4 were approximated by using the "natural" flow and temperature outputs from Segment 3, and by augmenting riparian vegetation along the entire reach.
- *Segment 5 (Helena WWTP Outfall to the Mouth)* – Natural conditions in Segment 5 were approximated by using the "natural" flow and temperature outputs from Segment 4, and by augmenting riparian vegetation along the entire reach.

Table G-9. SSTEMP input variables for modeled natural conditions.

Input Parameter	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Segment Inflow (cfs)	8.55	18.9	19.8	19.8	21.3
Segment Outflow (cfs)	9.9	19.8	19.8	21.3	36.3
Inflow Temperature (ºF)	55.0	64.3	65.62	66.52	67.65
Accretion Temperature (ºF)	53.0	53.0	53.0	53.0	55
Latitude (degrees)	46.55	46.57	46.59	46.62	46.66
Dam at Head of Segment	Not checked	Not checked	Checked	Not checked	Not checked
Segment Length	7.40	2.28	1.56	5.25	6.83
Upstream Elevation (ft)	4195	3975	3900	3838	3708
Downstream Elevation (ft)	3975	3900	3838	3708	3650
Width's A Term (s/ft^2)	16.7	17.0	15	14.4	15
B Term	0.099	0.10	0.11	0.11	0.19
Manning's n	0.034	0.032	0.035	0.035	0.034
Air Temperature (° F)	77.28	77.81	78.06	78.40	78.74
Maximum Air Temperature (° F)	Not checked	Not checked	Not checked	Not checked	Not checked
Relative Humidity (%)	34.0	33.4	33.2	32.8	32.4
Wind Speed (mph)	7.1	7.1	7.1	7.1	7.1
Ground Temperature (° F)	55	55	55	55	55
Thermal Gradient (j/m^2/s/C)	1.65	1.65	1.65	1.65	1.65
Possible Sun (%)	90	90	90	90	90
Dust Coefficient	5	5	5	5	5
Ground Reflectivity (%)	25	25	25	25	25

Table G-10. SSTEMP shading variables for modeled natural conditions.

Parameter	Segment 1		Segment 2		Segment 3		Segment 4		Segment 5	
Segment Azimuth (degrees)	45		0		-22.5		-45		30	
	West	East	West	East	West	East	West	East	West	East
Topographic Altitude (degrees)	12	10	12	10	13	10	15	10	10	10
Vegetation Height (ft)	15	25	15	15	10	20	15	10	25	15
Vegetation Crown (ft)	10	15	10	15	10	15	10	10	10	10
Vegetation Offset (ft)	2	1	2	3	2	2	2	2	5	2
Vegetation Density (%)	60	65	55	50	50	60	55	65	50	55

Modeled natural conditions in Prickly Pear Creek were then compared to the modeled existing conditions (Table G-11). Anthropogenic sources present from McClellan Creek to the Wylie Drive Bridge increase the daily average stream temperatures anywhere from 0.5 °F to 2.7 °F. When model uncertainties are accounted for, worst-case scenarios reveal that temperatures may be as much as 3.2 degrees Fahrenheit greater than natural conditions. Natural stream temperatures from the Wylie Drive Bridge to the mouth could not be compared to existing temperatures because the stream is currently dewatered, and segments are not hydrologically connected during summer low flow months.

Table G-11. Modeled current versus natural daily average stream temperatures in Prickly Pear Creek for a critical summer low flow event.

303(d) Segment	Modeling Segment	Avg Modeled Temperature – Natural	Avg Modeled Temperature – Existing	Difference (Natural-Existing)	Percent Difference	Changes Needed To Achieve Natural Conditions
MT41I006_040	Segment 1 – Lump Gulch to McClellan Creek	65.7 ° F	65.7 ° F	0.0 ° F	0.0%	None.
	Segment 2 – McClellan Creek to ASARCO Dam	65.6 ° F	67.2 ° F	-1.6 ° F	2.2%	Increase vegetation density with no loss of flow and gain 0.9 cfs.
	Segment 3 – ASARCO Dam to Wylie Drive	66.5 ° F	69.2 ° F	-2.7 ° F	3.8%	Increase vegetation density with inflow from restoration in upstream segment.
MT41I006_030	Segment 4 – Wylie Drive to Helena WWTP Outfall	67.7 ° F	Dewatered – Could Not Be Calibrated/ Evaluated	NA	NA	Increase vegetation density with inflow from restoration in upstream segment. No loss of flow and gain 1.5 cfs.
MT41I006_020	Segment 5 – Helena WWTP Outfall to Mouth	65.8 ° F[1]	Dewatered – Could Not Be Calibrated/ Evaluated	NA	NA	Increase vegetation density with inflow from restoration in upstream segment. Gain 15 cfs.

[1] Natural stream temperature decreases from Segment 4 to 5 because of cold-water groundwater inputs.

3.2 Restoration Strategy

An overall decrease of 2.2 °F in water temperature is needed in Prickly Pear Creek from McClellan Creek to Wylie Drive. A TMDL restoration strategy was modeled for Prickly Pear Creek from Lump Gulch to Wylie Drive (303(d) listed segment MT41I006_040). The restoration strategy involves a combination of maintaining some in-stream flows and enhancing the riparian vegetation along this section of Prickly Pear Creek. No more than 10 percent of the in-stream flow was diverted within a reach and shading provided by enhancements to riparian vegetation was increased by an average of 40 percent. The final result is an average overall 2.2 °F decrease in stream temperature (Table G-12). A summary of this restoration strategy for each segment is provided below. The restoration values used for each segment are shown in Tables G-12 and G-13, and are summarized below.

- *Segment 1 (Lump Gulch to McClellan Creek)* – The field survey suggested that Prickly Pear Creek from Lump Gulch to McClellan Creek (Segment 1) was already in a natural condition, and did not require any adjustments to the model input parameters.
- *Segment 2 (McClellan Creek to the ASARCO Dam)* – Only 2.3 cfs of flow was diverted, and riparian density was enhanced along the entire reach.
- *Segment 3 (ASARCO Dam to Wylie Drive)* – Flow and temperature outputs from Segment 2 were used as model inputs, only 1.5 cfs of flow was diverted, and riparian density was enhanced along the entire reach.

Table G-12. Modeled current average daily stream temperatures in Prickly Pear Creek versus potential TMDL restoration for a critical summer low flow event.

303(d) Segment	Modeling Segment	Average Modeled Temperature – Restoration	Average Modeled Temperature – Existing	Difference (Restoration-Existing)	Percent Difference	Changes Needed To Achieve Natural Conditions
MT41I006_040	Segment 1 – Lump Gulch to McClellan Creek	65.7 ° F	65.7 ° F	0.0 ° F	0.0%	None.
MT41I006_040	Segment 2 – McClellan Creek to ASARCO Dam	66.1 ° F	67.2 ° F	-1.1 ° F	1.5%	Increase vegetation density with a loss of only 2.3 cfs.
MT41I006_040	Segment 3 – ASARCO Dam to Wylie Drive	67.0 ° F	69.2 ° F	-2.2 ° F	3.1%	Increase vegetation density with a loss of only 1.5 cfs. Inflow from restoration in upstream segment.
MT41I006_030						
MT41I006_020						

Table G-13. SSTEMP input variables for the TMDL restoration strategy for Prickly Pear Creek from Lump Gulch to Wylie Drive.

Input Parameter	Segment 1	Segment 2	Segment 3
Segment Inflow (cfs)	8.55	18.9	17.5
Segment Outflow (cfs)	9.9	17.5	16.0
Inflow Temperature (°F)	55.0	64.3	66.1
Accretion Temperature (°F)	53.0	53.0	53.0
Latitude (degrees)	46.55	46.57	46.59
Dam at Head of Segment	Not checked	Not checked	Checked
Segment Length	7.40	2.28	1.56
Upstream Elevation (ft)	4195	3975	3900
Downstream Elevation (ft)	3975	3900	3838
Width's A Term (s/ft^2)	16.7	17.0	15
B Term	0.099	0.10	0.11
Manning's n	0.034	0.032	0.035
Air Temperature (° F)	77.28	77.81	78.06
Maximum Air Temperature (° F)	Not checked	Not checked	Not checked
Relative Humidity (%)	34.0	33.4	33.2
Wind Speed (mph)	7.1	7.1	7.1
Ground Temperature (° F)	55	55	55
Thermal Gradient (j/m^2/s/C)	1.65	1.65	1.65
Possible Sun (%)	90	90	90
Dust Coefficient	5	5	5
Ground Reflectivity (%)	25	25	25

Table G-14. SSTEMP shading variables for the TMDL restoration strategy for Prickly Pear Creek from Lump Gulch to Wylie Drive.

Parameter	Segment 1		Segment 2		Segment 3	
Segment Azimuth (degrees)	45		0		-22.5	
Topographic Altitude (degrees)	West	East	West	East	West	East
	12	10	12	10	13	10
Vegetation Height (ft)	15	25	15	15	10	20
Vegetation Crown (ft)	10	15	10	15	10	15
Vegetation Offset (ft)	2	1	2	3	2	2
Vegetation Density (%)	60	65	55	50	50	60

4.0 REFERENCES

ARM. 2002. *Surface Water Quality Standards and Procedures.* Administrative Rules of Montana 17.30 601-646, Helena, Montana.

Barnes, H.H. 1967. Characteristics of Natural Channels. U.S. Geological Survey Water Supply Paper 1849. U.S. Government Printing Office, Washington, D.C.

Bartholow, J. 2002. Stream Segment Temperature Model (SSTEMP), Version 2.0, User's Manual. United States Geological Survey, Fort Collins Science Center Online, Fort Collins, CO http://www.fort.usgs.gov/products/training/if312.asp.

Berkas, Wayne. 2005. Personal communication with Land & Water Consulting, Inc. for discontinued USGS Prickly Pear Creek Gage Station Data.

Breeden, Randy. 2005. Personal communication with Land & Water Consulting, Inc. for USEPA ASARCO Superfund monitoring data.

EPA. 2004. STORET water quality data for the Lake Helena Watershed through 2004. U.S. Environmental Protection Agency. Online data available at, http://www.epa.gov/storet/dbtop.html. Internal data (2003-2004) submitted to DEQ for upload into STORET.

Montana Department of Natural Resources and Conservation. 2005. DNRC Water Right Query System [Online]. Available at http://nris.mt.gov/dnrc/waterrights/default.aspx.

Nickel, Jon. 2005. Personal communication with Land & Water Consulting, Inc. for anecdotal information on irrigation diversions from ASARCO's upper holding pond on Prickly Pear Creek.

Rosgen, D. L. 1994. A Classification of Natural Rivers. Catena 22:169-199. Elsevier, Amsterdam.

USGS. 2003. National Water Information System [Online]. U. S. Geological Survey. Available at http://waterdata.usgs.gov/nwis/.

Weather Underground. 2004. Detailed History and Climate Data for Helena Regional Airport. Weather Underground website at http://www.wunderground.com. August 7th, 2003.

5.0 SSTEMP MODELING OUTPUT

Segment 1a, Prickly Pear Segment MT411006_040, from Lump Gulch to the USGS Gage

<u>Current conditions (Calibration/Natural)</u>

```
"English",      "Segment Inflow (cfs)",          "8.550"
"English",      "Inflow Temperature (°F)",        "55.000"
"English",      "Segment Outflow (cfs)",          "9.400"
"English",      "Accretion Temp. (°F)",          "53.000"
"English",      "Latitude (degrees)",          "46.510"
"English",      "Segment Length (mi)",           "3.750"
"English",      "Upstream Elevation (ft)",       "4195.00"
"English",      "Downstream Elevation (ft)",      "4067.00"
"English",      "Width's A Term (s/ft²)",        "16.700"
"English",      "  B Term where W = A*Q**B",      "0.098"
"English",      "Manning's n",                 "0.036"
"English",      "Air Temperature (°F)",          "77.280"
"English",      "Relative Humidity (%)",          "34.000"
"English",      "Wind Speed (mph)",              "7.100"
"English",      "Ground Temperature (°F)",        "55.000"
"English",      "Thermal gradient (j/m²/s/C)",    "1.650"
"English",      "Possible Sun (%)",              "90.000"
"English",      "Dust Coefficient",             "5.000"
"English",      "Ground Reflectivity (%)",        "25.000"
"English",      "Solar Radiation (Langleys/d)",   "632.105"
"English",      "Total Shade (%)",               "42.265"
"English",      "Segment Azimuth (degrees)",       "45.000"
"West Side Variables"
"English",      "Topographic Altitude (degrees)",  "6.000"
"English",      "Vegetation Height (ft)",         "10.000"
"English",      "Vegetation Crown (ft)",          "10.000"
"English",      "Vegetation Offset (ft)",        "1.000"
"English",      "Vegetation Density (%)",         "50.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",       "15.000"
"English",      "Topographic Altitude (degrees)",  "25.000"
"English",      "Vegetation Height (ft)",         "15.000"
"English",      "Vegetation Crown (ft)",          "1.000"
"English",      "Vegetation Offset (ft)",        "55.000"
"English",      " Maximum Air Temp (°F)",         "82.226"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
        "Predicted Mean (°F) = 63.95"
        "Estimated Maximum (°F) = 72.61"
```

```
    "Approximate Minimum (°F) = 55.29"
    "Mean Equilibrium (°F) = 68.88"
    "Maximum Equilibrium (°F) = 76.44"
    "Minimum Equilibrium (°F) = 61.32"

Sensitivity for mean temperature values (10% variation)    SSTEMP (2.0.8)
Original mean temperature = 63.95°F
                          Temperature change (°F)
                            if variable is:
Variable                  Decreased Increased  Relative Sensitivity
-----------------------------------------------------------------------------
Segment Inflow (cfs)           -0.17     +0.20 **
Inflow Temperature (°F)          -1.71     +1.81 **************
Segment Outflow (cfs)            +0.59     -0.62 *****
Accretion Temp. (°F)           -0.26     +0.26 **
Width's A Term (s/ft²)         -0.63     +0.67 *****
 B Term where W = A*Q**B          -0.15     +0.14 *
Manning's n                  +0.00     +0.00
Air Temperature (°F)           -3.86     +3.46 ******************************
Relative Humidity (%)            -0.60     +0.60 *****
Wind Speed (mph)               +0.07     -0.08 *
Ground Temperature (°F)           -0.20     +0.20 **
Thermal gradient (j/m²/s/C)       +0.02     -0.02
Possible Sun (%)              -0.22     +0.30 **
Dust Coefficient              +0.02     -0.02
Ground Reflectivity (%)          -0.02     +0.02
Segment Azimuth (degrees)         +0.03     -0.02
West Side:
Topographic Altitude (degrees)  +0.00      0.00
Vegetation Height (ft)          +0.03     -0.03
Vegetation Crown (ft)            +0.03     -0.03
Vegetation Offset (ft)          -0.01     +0.01
Vegetation Density (%)            +0.08     -0.08 *
East Side:
Topographic Altitude (degrees)  +0.01      0.00
Vegetation Height (ft)          +0.04     -0.06
Vegetation Crown (ft)            +0.05     -0.06
Vegetation Offset (ft)          -0.01     +0.01
Vegetation Density (%)            +0.30     -0.30 **
```

Segment 1b, Prickly Pear Segment MT41I006_040, from Lump Gulch to McClellan Creek

Current conditions (Calibration/Natural)

```
"English",     "Segment Inflow (cfs)",          "8.550"
"English",     "Inflow Temperature (°F)",         "55.000"
"English",     "Segment Outflow (cfs)",          "9.900"
"English",     "Accretion Temp. (°F)",          "53.000"
"English",     "Latitude (degrees)",          "46.550"
"English",     "Segment Length (mi)",           "7.400"
"English",     "Upstream Elevation (ft)",         "4195.00"
```

```
"English",     "Downstream Elevation (ft)",      "3975.00"
"English",     "Width's A Term (s/ft²)",        "16.700"
"English",     "  B Term where W = A*Q**B",        "0.099"
"English",     "Manning's n",              "0.034"
"English",     "Air Temperature (°F)",           "77.280"
"English",     "Relative Humidity (%)",          "34.000"
"English",     "Wind Speed (mph)",               "7.100"
"English",     "Ground Temperature (°F)",        "55.000"
"English",     "Thermal gradient (j/m²/s/C)",    "1.650"
"English",     "Possible Sun (%)",              "90.000"
"English",     "Dust Coefficient",              "5.000"
"English",     "Ground Reflectivity (%)",        "25.000"
"English",     "Solar Radiation (Langleys/d)",   "631.836"
"English",     "Total Shade (%)",               "51.103"
"English",     "Segment Azimuth (degrees)",      "45.000"
"West Side Variables"
"English",     "Topographic Altitude (degrees)",  "12.000"
"English",     "Vegetation Height (ft)",         "15.000"
"English",     "Vegetation Crown (ft)",          "10.000"
"English",     "Vegetation Offset (ft)",        "2.000"
"English",     "Vegetation Density (%)",         "60.000"
"East Side Variables"
"English",     "Segment Azimuth (degrees)",      "10.000"
"English",     "Topographic Altitude (degrees)",  "25.000"
"English",     "Vegetation Height (ft)",         "15.000"
"English",     "Vegetation Crown (ft)",          "1.000"
"English",     "Vegetation Offset (ft)",        "65.000"
"English",     " Maximum Air Temp (°F)",         "82.227"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
     "Predicted Mean (°F) = 65.70"
     "Estimated Maximum (°F) = 72.59"
     "Approximate Minimum (°F) = 58.81"
     "Mean Equilibrium (°F) = 67.75"
     "Maximum Equilibrium (°F) = 74.64"
     "Minimum Equilibrium (°F) = 60.87"

Sensitivity for mean temperature values (10% variation)    SSTEMP (2.0.8)
Original mean temperature = 65.70°F
                    Temperature change (°F)
                       if variable is:
Variable                Decreased Increased   Relative Sensitivity
----------------------------------------------------------------------
Segment Inflow (cfs)        -0.26    +0.27 **
Inflow Temperature (°F)      -0.57    +0.61 ****
Segment Outflow (cfs)        +0.51    -0.57 ****
Accretion Temp. (°F)        -0.29    +0.29 **
Width's A Term (s/ft²)      -0.53    +0.55 ***
```

```
 B Term where W = A*Q**B       -0.13    +0.11 *
Manning's n                 +0.00    +0.00
Air Temperature (°F)          -4.78    +4.45 ******************************
Relative Humidity (%)          -0.74    +0.75 *****
Wind Speed (mph)              +0.18    -0.19 *
Ground Temperature (°F)         -0.25    +0.25 **
Thermal gradient (j/m²/s/C)     +0.04    -0.04
Possible Sun (%)              -0.23    +0.32 **
Dust Coefficient             +0.02    -0.02
Ground Reflectivity (%)         -0.02    +0.02
Segment Azimuth (degrees)       +0.03    -0.03
West Side:
Topographic Altitude (degrees)  +0.01    -0.01
Vegetation Height (ft)          +0.04    -0.06
Vegetation Crown (ft)           +0.04    -0.04
Vegetation Offset (ft)         -0.02    +0.01
Vegetation Density (%)          +0.12    -0.12 *
East Side:
Topographic Altitude (degrees)  +0.00     0.00
Vegetation Height (ft)          +0.06    -0.10 *
Vegetation Crown (ft)           +0.06    -0.09 *
Vegetation Offset (ft)         -0.01    +0.01
Vegetation Density (%)          +0.45    -0.45 ***
```

Segment 2, Prickly Pear Segment MT41I006_040, from McClellan Creek to the ASARCO Dam

Current conditions

```
"English",      "Segment Inflow (cfs)",          "18.900"
"English",      "Inflow Temperature (°F)",        "64.300"
"English",      "Segment Outflow (cfs)",          "9.000"
"English",      "Accretion Temp. (°F)",           "53.000"
"English",      "Latitude (degrees)",           "46.570"
"English",      "Segment Length (mi)",            "2.280"
"English",      "Upstream Elevation (ft)",        "3975.00"
"English",      "Downstream Elevation (ft)",       "3900.00"
"English",      "Width's A Term (s/ft²)",         "17.000"
"English",      "  B Term where W = A*Q**B",      "0.100"
"English",      "Manning's n",                  "0.032"
"English",      "Air Temperature (°F)",           "77.810"
"English",      "Relative Humidity (%)",          "33.400"
"English",      "Wind Speed (mph)",              "7.100"
"English",      "Ground Temperature (°F)",         "55.000"
"English",      "Thermal gradient (j/m²/s/C)",     "1.650"
"English",      "Possible Sun (%)",              "90.000"
"English",      "Dust Coefficient",             "5.000"
"English",      "Ground Reflectivity (%)",         "25.000"
"English",      "Solar Radiation (Langleys/d)",    "631.479"
"English",      "Total Shade (%)",               "24.452"
"English",      "Segment Azimuth (degrees)",       "0.000"
```

```
"West Side Variables"
"English",      "Topographic Altitude (degrees)",  "12.000"
"English",      "Vegetation Height (ft)",       "15.000"
"English",      "Vegetation Crown (ft)",        "10.000"
"English",      "Vegetation Offset (ft)",       "3.000"
"English",      "Vegetation Density (%)",       "40.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",     "6.000"
"English",      "Topographic Altitude (degrees)",  "15.000"
"English",      "Vegetation Height (ft)",       "15.000"
"English",      "Vegetation Crown (ft)",        "5.000"
"English",      "Vegetation Offset (ft)",       "35.000"
"English",      " Maximum Air Temp (°F)",        "82.774"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
     "Predicted Mean (°F) = 67.18"
     "Estimated Maximum (°F) = 77.40"
     "Approximate Minimum (°F) = 56.95"
     "Mean Equilibrium (°F) = 71.34"
     "Maximum Equilibrium (°F) = 80.05"
     "Minimum Equilibrium (°F) = 62.62"

Sensitivity for mean temperature values (10% variation)    SSTEMP (2.0.8)
Original mean temperature = 67.18°F
                    Temperature change (°F)
                      if variable is:
Variable                 Decreased Increased   Relative Sensitivity
--------------------------------------------------------------------------------
Segment Inflow (cfs)          +0.09    -0.10 *
Inflow Temperature (°F)        -3.81    +4.00 ******************************
Segment Outflow (cfs)          +0.08    -0.09 *
Accretion Temp. (°F)          +0.00    +0.00
Width's A Term (s/ft^2)        -0.27    +0.28 **
 B Term where W = A*Q**B        -0.07    +0.07 *
Manning's n                 +0.00    +0.00
Air Temperature (°F)          -2.23    +1.97 *****************
Relative Humidity (%)          -0.35    +0.35 ***
Wind Speed (mph)              +0.11    -0.11 *
Ground Temperature (°F)         -0.11    +0.11 *
Thermal gradient (j/m^2/s/C)     +0.02    -0.02
Possible Sun (%)             -0.16    +0.22 **
Dust Coefficient            +0.01    -0.01
Ground Reflectivity (%)         -0.01    +0.01
Segment Azimuth (degrees)        +0.00    +0.00
West Side:
Topographic Altitude (degrees)   +0.01    -0.01
Vegetation Height (ft)         +0.02    -0.03
Vegetation Crown (ft)          +0.02    -0.02
Vegetation Offset (ft)          -0.01    +0.01
Vegetation Density (%)           +0.06    -0.06
East Side:
Topographic Altitude (degrees)   +0.00     0.00
Vegetation Height (ft)           +0.02    -0.02
Vegetation Crown (ft)            +0.02    -0.02
Vegetation Offset (ft)          -0.01    +0.01
Vegetation Density (%)           +0.06    -0.06
```

Natural conditions

```
"English",      "Segment Inflow (cfs)",           "18.900"
"English",      "Inflow Temperature (°F)",         "64.300"
"English",      "Segment Outflow (cfs)",           "19.800"
"English",      "Accretion Temp. (°F)",            "53.000"
"English",      "Latitude (degrees)",             "46.570"
"English",      "Segment Length (mi)",             "2.280"
"English",      "Upstream Elevation (ft)",         "3975.00"
"English",      "Downstream Elevation (ft)",        "3900.00"
"English",      "Width's A Term (s/ft²)",          "17.000"
"English",      "  B Term where W = A*Q**B",        "0.100"
"English",      "Manning's n",                   "0.032"
"English",      "Air Temperature (°F)",            "77.810"
"English",      "Relative Humidity (%)",           "33.400"
"English",      "Wind Speed (mph)",               "7.100"
"English",      "Ground Temperature (°F)",          "55.000"
"English",      "Thermal gradient (j/m²/s/C)",      "1.650"
"English",      "Possible Sun (%)",               "90.000"
"English",      "Dust Coefficient",               "5.000"
"English",      "Ground Reflectivity (%)",          "25.000"
"English",      "Solar Radiation (Langleys/d)",     "631.479"
"English",      "Total Shade (%)",                "35.681"
"English",      "Segment Azimuth (degrees)",        "0.000"
"West Side Variables"
"English",      "Topographic Altitude (degrees)",  "12.000"
"English",      "Vegetation Height (ft)",          "15.000"
"English",      "Vegetation Crown (ft)",           "10.000"
"English",      "Vegetation Offset (ft)",          "2.000"
"English",      "Vegetation Density (%)",          "55.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",        "10.000"
"English",      "Topographic Altitude (degrees)",  "15.000"
"English",      "Vegetation Height (ft)",          "15.000"
"English",      "Vegetation Crown (ft)",           "3.000"
"English",      "Vegetation Offset (ft)",          "50.000"
"English",      " Maximum Air Temp (°F)",           "82.774"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
```

```
    "Predicted Mean (°F) = 65.62"
    "Estimated Maximum (°F) = 73.70"
    "Approximate Minimum (°F) = 57.55"
    "Mean Equilibrium (°F) = 70.00"
    "Maximum Equilibrium (°F) = 77.97"
    "Minimum Equilibrium (°F) = 62.03"
```

<u>Restoration 1. Increase vegetation density</u>

```
"English",    "Segment Inflow (cfs)",           "18.900"
"English",    "Inflow Temperature (°F)",         "64.300"
"English",    "Segment Outflow (cfs)",          "9.000"
"English",    "Accretion Temp. (°F)",           "53.000"
"English",    "Latitude (degrees)",           "46.570"
"English",    "Segment Length (mi)",            "2.280"
"English",    "Upstream Elevation (ft)",        "3975.00"
"English",    "Downstream Elevation (ft)",        "3900.00"
"English",    "Width's A Term (s/ft²)",         "17.000"
"English",    "  B Term where W = A*Q**B",        "0.100"
"English",    "Manning's n",                  "0.032"
"English",    "Air Temperature (°F)",           "77.810"
"English",    "Relative Humidity (%)",           "33.400"
"English",    "Wind Speed (mph)",               "7.100"
"English",    "Ground Temperature (°F)",         "55.000"
"English",    "Thermal gradient (j/m²/s/C)",     "1.650"
"English",    "Possible Sun (%)",             "90.000"
"English",    "Dust Coefficient",            "5.000"
"English",    "Ground Reflectivity (%)",         "25.000"
"English",    "Solar Radiation (Langleys/d)",    "631.479"
"English",    "Total Shade (%)",              "36.283"
"English",    "Segment Azimuth (degrees)",       "0.000"
"West Side Variables"
"English",    "Topographic Altitude (degrees)",  "12.000"
"English",    "Vegetation Height (ft)",         "15.000"
"English",    "Vegetation Crown (ft)",           "10.000"
"English",    "Vegetation Offset (ft)",         "2.000"
"English",    "Vegetation Density (%)",          "55.000"
"East Side Variables"
"English",    "Segment Azimuth (degrees)",       "10.000"
"English",    "Topographic Altitude (degrees)",  "15.000"
"English",    "Vegetation Height (ft)",         "15.000"
"English",    "Vegetation Crown (ft)",           "3.000"
"English",    "Vegetation Offset (ft)",         "50.000"
"English",    " Maximum Air Temp (°F)",          "82.774"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
    "Predicted Mean (°F) = 66.57"
    "Estimated Maximum (°F) = 75.47"
```

```
      "Approximate Minimum (°F) = 57.67"
      "Mean Equilibrium (°F) = 69.93"
      "Maximum Equilibrium (°F) = 77.86"
      "Minimum Equilibrium (°F) = 62.00"
```

Restoration 2. No loss of outflow and gain 0.9cfs

```
"English",     "Segment Inflow (cfs)",           "18.900"
"English",     "Inflow Temperature (°F)",         "64.300"
"English",     "Segment Outflow (cfs)",           "19.800"
"English",     "Accretion Temp. (°F)",           "53.000"
"English",     "Latitude (degrees)",            "46.570"
"English",     "Segment Length (mi)",             "2.280"
"English",     "Upstream Elevation (ft)",         "3975.00"
"English",     "Downstream Elevation (ft)",        "3900.00"
"English",     "Width's A Term (s/ft²)",          "17.000"
"English",     "  B Term where W = A*Q**B",        "0.100"
"English",     "Manning's n",                  "0.032"
"English",     "Air Temperature (°F)",            "77.810"
"English",     "Relative Humidity (%)",            "33.400"
"English",     "Wind Speed (mph)",               "7.100"
"English",     "Ground Temperature (°F)",          "55.000"
"English",     "Thermal gradient (j/m²/s/C)",     "1.650"
"English",     "Possible Sun (%)",               "90.000"
"English",     "Dust Coefficient",              "5.000"
"English",     "Ground Reflectivity (%)",          "25.000"
"English",     "Solar Radiation (Langleys/d)",    "631.479"
"English",     "Total Shade (%)",                "24.013"
"English",     "Segment Azimuth (degrees)",       "0.000"
"West Side Variables"
"English",     "Topographic Altitude (degrees)",  "12.000"
"English",     "Vegetation Height (ft)",          "15.000"
"English",     "Vegetation Crown (ft)",           "10.000"
"English",     "Vegetation Offset (ft)",          "3.000"
"English",     "Vegetation Density (%)",           "40.000"
"East Side Variables"
"English",     "Segment Azimuth (degrees)",       "6.000"
"English",     "Topographic Altitude (degrees)",  "15.000"
"English",     "Vegetation Height (ft)",          "15.000"
"English",     "Vegetation Crown (ft)",           "5.000"
"English",     "Vegetation Offset (ft)",          "35.000"
"English",     " Maximum Air Temp (°F)",           "82.774"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
      "Predicted Mean (°F) = 66.08"
      "Estimated Maximum (°F) = 75.39"
      "Approximate Minimum (°F) = 56.78"
      "Mean Equilibrium (°F) = 71.39"
```

```
    "Maximum Equilibrium (°F) = 80.13"
    "Minimum Equilibrium (°F) = 62.65"
```

Restoration 3. TMDL Restoration Strategy

```
"English",     "Segment Inflow (cfs)",             "18.900"
"English",     "Inflow Temperature (°F)",          "64.300"
"English",     "Segment Outflow (cfs)",            "17.500"
"English",     "Accretion Temp. (°F)",             "53.000"
"English",     "Latitude (degrees)",             "46.570"
"English",     "Segment Length (mi)",              "2.280"
"English",     "Upstream Elevation (ft)",          "3975.00"
"English",     "Downstream Elevation (ft)",          "3900.00"
"English",     "Width's A Term (s/ft²)",           "17.000"
"English",     " B Term where W = A*Q**B",             "0.100"
"English",     "Manning's n",                    "0.032"
"English",     "Air Temperature (°F)",             "77.810"
"English",     "Relative Humidity (%)",            "33.400"
"English",     "Wind Speed (mph)",                 "7.100"
"English",     "Ground Temperature (°F)",            "55.000"
"English",     "Thermal gradient (j/m²/s/C)",      "1.650"
"English",     "Possible Sun (%)",                 "90.000"
"English",     "Dust Coefficient",                "5.000"
"English",     "Ground Reflectivity (%)",          "25.000"
"English",     "Solar Radiation (Langleys/d)",     "631.479"
"English",     "Total Shade (%)",                 "35.804"
"English",     "Segment Azimuth (degrees)",          "0.000"
"West Side Variables"
"English",     "Topographic Altitude (degrees)",  "12.000"
"English",     "Vegetation Height (ft)",           "15.000"
"English",     "Vegetation Crown (ft)",             "10.000"
"English",     "Vegetation Offset (ft)",          "2.000"
"English",     "Vegetation Density (%)",            "55.000"
"East Side Variables"
"English",     "Segment Azimuth (degrees)",          "10.000"
"English",     "Topographic Altitude (degrees)",  "15.000"
"English",     "Vegetation Height (ft)",           "15.000"
"English",     "Vegetation Crown (ft)",             "3.000"
"English",     "Vegetation Offset (ft)",          "50.000"
"English",     " Maximum Air Temp (°F)",            "82.774"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
    "Predicted Mean (°F) = 66.13"
    "Estimated Maximum (°F) = 74.26"
    "Approximate Minimum (°F) = 58.00"
    "Mean Equilibrium (°F) = 69.99"
    "Maximum Equilibrium (°F) = 77.95"
    "Minimum Equilibrium (°F) = 62.02"
```

Segment 3, Prickly Pear Segment MT41I006_040, from the ASARCO Dam to Wyle Drive

Current conditions

```
"English",     "Segment Inflow (cfs)",          "9.000"
"English",     "Inflow Temperature (°F)",         "67.180"
"English",     "Segment Outflow (cfs)",          "3.000"
"English",     "Accretion Temp. (°F)",           "53.000"
"English",     "Latitude (degrees)",           "46.590"
"English",     "Segment Length (mi)",           "1.560"
"English",     "Upstream Elevation (ft)",        "3900.00"
"English",     "Downstream Elevation (ft)",       "3838.00"
"English",     "Width's A Term (s/ft^2)",         "15.000"
"English",     "  B Term where W = A*Q**B",       "0.110"
"English",     "Manning's n",                 "0.035"
"English",     "Air Temperature (°F)",           "78.060"
"English",     "Relative Humidity (%)",          "33.200"
"English",     "Wind Speed (mph)",              "7.100"
"English",     "Ground Temperature (°F)",         "55.000"
"English",     "Thermal gradient (j/m^2/s/C)",     "1.650"
"English",     "Possible Sun (%)",              "90.000"
"English",     "Dust Coefficient",              "5.000"
"English",     "Ground Reflectivity (%)",         "25.000"
"English",     "Solar Radiation (Langleys/d)",    "631.181"
"English",     "Total Shade (%)",               "27.525"
"English",     "Segment Azimuth (degrees)",       "-22.500"
"West Side Variables"
"English",     "Topographic Altitude (degrees)",  "13.000"
"English",     "Vegetation Height (ft)",          "10.000"
"English",     "Vegetation Crown (ft)",           "10.000"
"English",     "Vegetation Offset (ft)",          "2.000"
"English",     "Vegetation Density (%)",          "30.000"
"East Side Variables"
"English",     "Segment Azimuth (degrees)",       "6.000"
"English",     "Topographic Altitude (degrees)",  "20.000"
"English",     "Vegetation Height (ft)",          "15.000"
"English",     "Vegetation Crown (ft)",           "4.000"
"English",     "Vegetation Offset (ft)",          "50.000"
"English",     " Maximum Air Temp (°F)",          "83.031"
"Dam at Head of Segment","Checked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
      "Predicted Mean (°F) = 69.18"
      "Estimated Maximum (°F) = 74.26"
      "Approximate Minimum (°F) = 64.11"
      "Mean Equilibrium (°F) = 71.01"
      "Maximum Equilibrium (°F) = 79.52"
      "Minimum Equilibrium (°F) = 62.50"
```

```
Sensitivity for mean temperature values (10% variation)    SSTEMP (2.0.8)
Original mean temperature = 69.18°F
                         Temperature change (°F)
                           if variable is:
Variable                    Decreased Increased   Relative Sensitivity
-----------------------------------------------------------------------------
Segment Inflow (cfs)           +0.05    -0.06 *
Inflow Temperature (°F)         -3.15    +3.38 ******************************
Segment Outflow (cfs)           +0.05    -0.05
Accretion Temp. (°F)           +0.00    +0.00
Width's A Term (s/ft²)         -0.21    +0.21 **
 B Term where W = A*Q**B          -0.04    +0.04
Manning's n                 +0.00    +0.00
Air Temperature (°F)           -2.79    +2.48 ************************
Relative Humidity (%)           -0.43    +0.43 ****
Wind Speed (mph)               +0.19    -0.19 **
Ground Temperature (°F)           -0.14    +0.14 *
Thermal gradient (j/m²/s/C)       +0.03    -0.03
Possible Sun (%)             -0.19    +0.27 **
Dust Coefficient              +0.02    -0.02
Ground Reflectivity (%)          -0.02    +0.02
Segment Azimuth (degrees)         -0.02    +0.02
West Side:
Topographic Altitude (degrees)   +0.01    -0.01
Vegetation Height (ft)          +0.03    -0.03
Vegetation Crown (ft)           +0.02    -0.02
Vegetation Offset (ft)         -0.01    +0.01
Vegetation Density (%)          +0.07    -0.07 *
East Side:
Topographic Altitude (degrees)   +0.00     0.00
Vegetation Height (ft)          +0.02    -0.02
Vegetation Crown (ft)           +0.03    -0.03
Vegetation Offset (ft)         -0.01    +0.01
Vegetation Density (%)          +0.10    -0.10 *
```

Natural conditions

```
"English",     "Segment Inflow (cfs)",          "19.800"
"English",     "Inflow Temperature (°F)",         "65.620"
"English",     "Segment Outflow (cfs)",          "19.800"
"English",     "Accretion Temp. (°F)",          "53.000"
"English",     "Latitude (degrees)",          "46.590"
"English",     "Segment Length (mi)",           "1.560"
"English",     "Upstream Elevation (ft)",        "3900.00"
"English",     "Downstream Elevation (ft)",       "3838.00"
"English",     "Width's A Term (s/ft²)",        "15.000"
"English",     "  B Term where W = A*Q**B",      "0.110"
"English",     "Manning's n",               "0.035"
"English",     "Air Temperature (°F)",          "78.060"
"English",     "Relative Humidity (%)",          "33.200"
"English",     "Wind Speed (mph)",            "7.100"
```

```
"English",     "Ground Temperature (°F)",          "55.000"
"English",     "Thermal gradient (j/m²/s/C)",      "1.650"
"English",     "Possible Sun (%)",                 "90.000"
"English",     "Dust Coefficient",                 "5.000"
"English",     "Ground Reflectivity (%)",          "25.000"
"English",     "Solar Radiation (Langleys/d)",     "631.181"
"English",     "Total Shade (%)",                  "36.587"
"English",     "Segment Azimuth (degrees)",        "-22.500"
"West Side Variables"
"English",     "Topographic Altitude (degrees)",   "13.000"
"English",     "Vegetation Height (ft)",           "10.000"
"English",     "Vegetation Crown (ft)",            "10.000"
"English",     "Vegetation Offset (ft)",           "2.000"
"English",     "Vegetation Density (%)",           "50.000"
"East Side Variables"
"English",     "Segment Azimuth (degrees)",        "10.000"
"English",     "Topographic Altitude (degrees)",   "20.000"
"English",     "Vegetation Height (ft)",           "15.000"
"English",     "Vegetation Crown (ft)",            "2.000"
"English",     "Vegetation Offset (ft)",           "60.000"
"English",     " Maximum Air Temp (°F)",           "83.031"
"Dam at Head of Segment","Checked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
    "Predicted Mean (°F) = 66.52"
    "Estimated Maximum (°F) = 68.60"
    "Approximate Minimum (°F) = 64.45"
    "Mean Equilibrium (°F) = 70.10"
    "Maximum Equilibrium (°F) = 77.97"
    "Minimum Equilibrium (°F) = 62.22"
```

Restoration 4. Increase vegetation density, with inflow from restoration 1 in upstream segment

```
"English",     "Segment Inflow (cfs)",             "9.000"
"English",     "Inflow Temperature (°F)",          "66.570"
"English",     "Segment Outflow (cfs)",            "3.000"
"English",     "Accretion Temp. (°F)",             "53.000"
"English",     "Latitude (degrees)",               "46.590"
"English",     "Segment Length (mi)",              "1.560"
"English",     "Upstream Elevation (ft)",          "3900.00"
"English",     "Downstream Elevation (ft)",        "3838.00"
"English",     "Width's A Term (s/ft²)",           "15.000"
"English",     "  B Term where W = A*Q**B",        "0.110"
"English",     "Manning's n",                      "0.035"
"English",     "Air Temperature (°F)",             "78.060"
"English",     "Relative Humidity (%)",            "33.200"
"English",     "Wind Speed (mph)",                 "7.100"
"English",     "Ground Temperature (°F)",          "55.000"
"English",     "Thermal gradient (j/m²/s/C)",      "1.650"
```

```
"English",      "Possible Sun (%)",              "90.000"
"English",      "Dust Coefficient",             "5.000"
"English",      "Ground Reflectivity (%)",        "25.000"
"English",      "Solar Radiation (Langleys/d)",    "631.181"
"English",      "Total Shade (%)",               "39.130"
"English",      "Segment Azimuth (degrees)",        "-22.500"
"West Side Variables"
"English",      "Topographic Altitude (degrees)",  "13.000"
"English",      "Vegetation Height (ft)",         "10.000"
"English",      "Vegetation Crown (ft)",          "10.000"
"English",      "Vegetation Offset (ft)",        "2.000"
"English",      "Vegetation Density (%)",         "50.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",       "10.000"
"English",      "Topographic Altitude (degrees)",  "20.000"
"English",      "Vegetation Height (ft)",         "15.000"
"English",      "Vegetation Crown (ft)",          "2.000"
"English",      "Vegetation Offset (ft)",        "60.000"
"English",      " Maximum Air Temp (°F)",         "83.031"
"Dam at Head of Segment","Checked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
        "Predicted Mean (°F) = 68.14"
        "Estimated Maximum (°F) = 72.56"
        "Approximate Minimum (°F) = 63.72"
        "Mean Equilibrium (°F) = 69.62"
        "Maximum Equilibrium (°F) = 77.34"
        "Minimum Equilibrium (°F) = 61.90"
```

Restoration 5. Inflow from restoration 2 in upstream segment

```
"English",      "Segment Inflow (cfs)",           "19.800"
"English",      "Inflow Temperature (°F)",         "66.080"
"English",      "Segment Outflow (cfs)",          "19.800"
"English",      "Accretion Temp. (°F)",           "53.000"
"English",      "Latitude (degrees)",            "46.590"
"English",      "Segment Length (mi)",            "1.560"
"English",      "Upstream Elevation (ft)",        "3900.00"
"English",      "Downstream Elevation (ft)",       "3838.00"
"English",      "Width's A Term (s/ft²)",         "15.000"
"English",      "  B Term where W = A*Q**B",       "0.110"
"English",      "Manning's n",                  "0.035"
"English",      "Air Temperature (°F)",           "78.060"
"English",      "Relative Humidity (%)",          "33.200"
"English",      "Wind Speed (mph)",              "7.100"
"English",      "Ground Temperature (°F)",         "55.000"
"English",      "Thermal gradient (j/m²/s/C)",     "1.650"
"English",      "Possible Sun (%)",              "90.000"
"English",      "Dust Coefficient",             "5.000"
```

```
"English",      "Ground Reflectivity (%)",        "25.000"
"English",      "Solar Radiation (Langleys/d)",   "631.181"
"English",      "Total Shade (%)",                "25.777"
"English",      "Segment Azimuth (degrees)",      "-22.500"
"West Side Variables"
"English",      "Topographic Altitude (degrees)", "13.000"
"English",      "Vegetation Height (ft)",         "10.000"
"English",      "Vegetation Crown (ft)",          "10.000"
"English",      "Vegetation Offset (ft)",         "2.000"
"English",      "Vegetation Density (%)",         "30.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",      "6.000"
"English",      "Topographic Altitude (degrees)", "20.000"
"English",      "Vegetation Height (ft)",         "15.000"
"English",      "Vegetation Crown (ft)",          "4.000"
"English",      "Vegetation Offset (ft)",         "50.000"
"English",      " Maximum Air Temp (°F)",         "83.031"
"Dam at Head of Segment","Checked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
        "Predicted Mean (°F) = 67.17"
        "Estimated Maximum (°F) = 69.56"
        "Approximate Minimum (°F) = 64.78"
        "Mean Equilibrium (°F) = 71.38"
        "Maximum Equilibrium (°F) = 79.97"
        "Minimum Equilibrium (°F) = 62.79"
```

Restoration 6. TMDL Restoration Strategy with inflow from restoration 3 in upstream segment

```
"English",      "Segment Inflow (cfs)",           "17.500"
"English",      "Inflow Temperature (°F)",        "66.130"
"English",      "Segment Outflow (cfs)",          "16.000"
"English",      "Accretion Temp. (°F)",           "53.000"
"English",      "Latitude (degrees)",             "46.590"
"English",      "Segment Length (mi)",            "1.560"
"English",      "Upstream Elevation (ft)",        "3900.00"
"English",      "Downstream Elevation (ft)",      "3838.00"
"English",      "Width's A Term (s/ft^2)",        "15.000"
"English",      "  B Term where W = A*Q**B",      "0.110"
"English",      "Manning's n",                    "0.035"
"English",      "Air Temperature (°F)",           "78.060"
"English",      "Relative Humidity (%)",          "33.200"
"English",      "Wind Speed (mph)",               "7.100"
"English",      "Ground Temperature (°F)",        "55.000"
"English",      "Thermal gradient (j/m^2/s/C)",   "1.650"
"English",      "Possible Sun (%)",               "90.000"
"English",      "Dust Coefficient",               "5.000"
"English",      "Ground Reflectivity (%)",        "25.000"
"English",      "Solar Radiation (Langleys/d)",   "631.181"
```

```
"English",      "Total Shade (%)",              "36.972"
"English",      "Segment Azimuth (degrees)",      "-22.500"
"West Side Variables"
"English",      "Topographic Altitude (degrees)",  "13.000"
"English",      "Vegetation Height (ft)",         "10.000"
"English",      "Vegetation Crown (ft)",          "10.000"
"English",      "Vegetation Offset (ft)",        "2.000"
"English",      "Vegetation Density (%)",          "50.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",      "10.000"
"English",      "Topographic Altitude (degrees)",  "20.000"
"English",      "Vegetation Height (ft)",         "15.000"
"English",      "Vegetation Crown (ft)",          "2.000"
"English",      "Vegetation Offset (ft)",        "60.000"
"English",      " Maximum Air Temp (°F)",         "83.031"
"Dam at Head of Segment","Checked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
     "Predicted Mean (°F) = 67.03"
     "Estimated Maximum (°F) = 69.35"
     "Approximate Minimum (°F) = 64.71"
     "Mean Equilibrium (°F) = 70.02"
     "Maximum Equilibrium (°F) = 77.87"
     "Minimum Equilibrium (°F) = 62.16"
```

Segment 4, Prickly Pear Segment MT41I006_030

Current conditions

```
"English",      "Segment Inflow (cfs)",           "3.000"
"English",      "Inflow Temperature (°F)",          "69.180"
"English",      "Segment Outflow (cfs)",           "1.500"
"English",      "Accretion Temp. (°F)",           "53.000"
"English",      "Latitude (degrees)",            "46.620"
"English",      "Segment Length (mi)",            "5.250"
"English",      "Upstream Elevation (ft)",         "3838.00"
"English",      "Downstream Elevation (ft)",        "3708.00"
"English",      "Width's A Term (s/ft²)",         "14.400"
"English",      "  B Term where W = A*Q**B",        "0.110"
"English",      "Manning's n",                 "0.036"
"English",      "Air Temperature (°F)",           "78.400"
"English",      "Relative Humidity (%)",           "32.800"
"English",      "Wind Speed (mph)",               "7.100"
"English",      "Ground Temperature (°F)",          "55.000"
"English",      "Thermal gradient (j/m²/s/C)",     "1.650"
"English",      "Possible Sun (%)",               "90.000"
"English",      "Dust Coefficient",              "5.000"
"English",      "Ground Reflectivity (%)",         "25.000"
"English",      "Solar Radiation (Langleys/d)",    "630.897"
```

```
"English",      "Total Shade (%)",              "9.481"
"English",      "Segment Azimuth (degrees)",      "-45.000"
"West Side Variables"
"English",      "Topographic Altitude (degrees)", "6.000"
"English",      "Vegetation Height (ft)",         "15.000"
"English",      "Vegetation Crown (ft)",          "10.000"
"English",      "Vegetation Offset (ft)",         "5.000"
"English",      "Vegetation Density (%)",         "15.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",      "6.000"
"English",      "Topographic Altitude (degrees)", "10.000"
"English",      "Vegetation Height (ft)",         "10.000"
"English",      "Vegetation Crown (ft)",          "10.000"
"English",      "Vegetation Offset (ft)",         "30.000"
"English",      " Maximum Air Temp (°F)",         "83.382"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
     "Predicted Mean (°F) = 73.06"
     "Estimated Maximum (°F) = 82.67"
     "Approximate Minimum (°F) = 63.46"
     "Mean Equilibrium (°F) = 73.08"
     "Maximum Equilibrium (°F) = 82.68"
     "Minimum Equilibrium (°F) = 63.47"

Sensitivity for mean temperature values (10% variation)   SSTEMP (2.0.8)
Original mean temperature = 73.06°F
                     Temperature change (°F)
                        if variable is:
Variable                 Decreased Increased  Relative Sensitivity
---------------------------------------------------------------------------
Segment Inflow (cfs)            0.00    +0.01
Inflow Temperature (°F)          -0.02    +0.02
Segment Outflow (cfs)           +0.00    +0.00
Accretion Temp. (°F)            +0.00    +0.00
Width's A Term (s/ft²)          -0.05    +0.07
 B Term where W = A*Q**B          -0.01    +0.01
Manning's n                  +0.00    +0.00
Air Temperature (°F)            -4.72    +4.57 ******************************
Relative Humidity (%)            -0.77    +0.79 *****
Wind Speed (mph)                +0.50    -0.54 ***
Ground Temperature (°F)           -0.24    +0.25 **
Thermal gradient (j/m²/s/C)       +0.08    -0.08 *
Possible Sun (%)              -0.42    +0.59 ****
Dust Coefficient              +0.03    -0.03
Ground Reflectivity (%)          -0.04    +0.04
Segment Azimuth (degrees)          -0.02    +0.02
West Side:
Topographic Altitude (degrees)   +0.00     0.00
```

```
Vegetation Height (ft)        +0.04    -0.04
Vegetation Crown (ft)          +0.03    -0.03
Vegetation Offset (ft)        -0.03    +0.03
Vegetation Density (%)         +0.07    -0.07
East Side:
Topographic Altitude (degrees)   +0.00     0.00
Vegetation Height (ft)        +0.03    -0.03
Vegetation Crown (ft)          +0.02    -0.01
Vegetation Offset (ft)        -0.02    +0.03
Vegetation Density (%)         +0.03    -0.03
```

Natural conditions

```
"English",     "Segment Inflow (cfs)",          "19.800"
"English",     "Inflow Temperature (°F)",         "66.520"
"English",     "Segment Outflow (cfs)",          "21.300"
"English",     "Accretion Temp. (°F)",           "53.000"
"English",     "Latitude (degrees)",           "46.620"
"English",     "Segment Length (mi)",            "5.250"
"English",     "Upstream Elevation (ft)",        "3838.00"
"English",     "Downstream Elevation (ft)",       "3708.00"
"English",     "Width's A Term (s/ft²)",         "14.400"
"English",     "  B Term where W = A*Q**B",       "0.110"
"English",     "Manning's n",                "0.035"
"English",     "Air Temperature (°F)",           "78.400"
"English",     "Relative Humidity (%)",          "32.800"
"English",     "Wind Speed (mph)",             "7.100"
"English",     "Ground Temperature (°F)",         "55.000"
"English",     "Thermal gradient (j/m²/s/C)",     "1.650"
"English",     "Possible Sun (%)",             "90.000"
"English",     "Dust Coefficient",             "5.000"
"English",     "Ground Reflectivity (%)",         "25.000"
"English",     "Solar Radiation (Langleys/d)",    "630.897"
"English",     "Total Shade (%)",              "36.419"
"English",     "Segment Azimuth (degrees)",       "-45.000"
"West Side Variables"
"English",     "Topographic Altitude (degrees)",  "15.000"
"English",     "Vegetation Height (ft)",         "15.000"
"English",     "Vegetation Crown (ft)",          "10.000"
"English",     "Vegetation Offset (ft)",         "2.000"
"English",     "Vegetation Density (%)",         "55.000"
"East Side Variables"
"English",     "Segment Azimuth (degrees)",       "10.000"
"English",     "Topographic Altitude (degrees)",  "10.000"
"English",     "Vegetation Height (ft)",         "10.000"
"English",     "Vegetation Crown (ft)",          "2.000"
"English",     "Vegetation Offset (ft)",         "65.000"
"English",     " Maximum Air Temp (°F)",          "83.382"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
```

```
"Total Shade","Disabled"
"Month/day","08/07"
        "Predicted Mean (°F) = 67.65"
        "Estimated Maximum (°F) = 74.36"
        "Approximate Minimum (°F) = 60.93"
        "Mean Equilibrium (°F) = 70.12"
        "Maximum Equilibrium (°F) = 78.00"
        "Minimum Equilibrium (°F) = 62.23"
```

Restoration 7. Increase vegetation density with inflow from restoration 4 in segment MT41I006_040

```
"English",     "Segment Inflow (cfs)",           "3.000"
"English",     "Inflow Temperature (°F)",        "68.140"
"English",     "Segment Outflow (cfs)",          "1.500"
"English",     "Accretion Temp. (°F)",           "53.000"
"English",     "Latitude (degrees)",             "46.620"
"English",     "Segment Length (mi)",            "5.250"
"English",     "Upstream Elevation (ft)",        "3838.00"
"English",     "Downstream Elevation (ft)",      "3708.00"
"English",     "Width's A Term (s/ft²)",         "14.400"
"English",     "  B Term where W = A*Q**B",      "0.110"
"English",     "Manning's n",                    "0.036"
"English",     "Air Temperature (°F)",           "78.400"
"English",     "Relative Humidity (%)",          "32.800"
"English",     "Wind Speed (mph)",               "7.100"
"English",     "Ground Temperature (°F)",        "55.000"
"English",     "Thermal gradient (j/m²/s/C)",    "1.650"
"English",     "Possible Sun (%)",               "90.000"
"English",     "Dust Coefficient",               "5.000"
"English",     "Ground Reflectivity (%)",        "25.000"
"English",     "Solar Radiation (Langleys/d)",   "630.897"
"English",     "Total Shade (%)",                "41.961"
"English",     "Segment Azimuth (degrees)",      "-45.000"
"West Side Variables"
"English",     "Topographic Altitude (degrees)", "15.000"
"English",     "Vegetation Height (ft)",         "15.000"
"English",     "Vegetation Crown (ft)",          "10.000"
"English",     "Vegetation Offset (ft)",         "2.000"
"English",     "Vegetation Density (%)",         "55.000"
"East Side Variables"
"English",     "Segment Azimuth (degrees)",      "10.000"
"English",     "Topographic Altitude (degrees)", "10.000"
"English",     "Vegetation Height (ft)",         "10.000"
"English",     "Vegetation Crown (ft)",          "2.000"
"English",     "Vegetation Offset (ft)",         "65.000"
"English",     " Maximum Air Temp (°F)",         "83.382"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
```

```
     "Predicted Mean (°F) = 69.26"
     "Estimated Maximum (°F) = 76.77"
     "Approximate Minimum (°F) = 61.75"
     "Mean Equilibrium (°F) = 69.27"
     "Maximum Equilibrium (°F) = 76.79"
     "Minimum Equilibrium (°F) = 61.75"
```

Restoration 8. Inflow from restoration 5 in segment MT41I006_040

```
"English",    "Segment Inflow (cfs)",          "19.800"
"English",    "Inflow Temperature (°F)",        "67.170"
"English",    "Segment Outflow (cfs)",          "21.300"
"English",    "Accretion Temp. (°F)",          "53.000"
"English",    "Latitude (degrees)",           "46.620"
"English",    "Segment Length (mi)",           "5.250"
"English",    "Upstream Elevation (ft)",        "3838.00"
"English",    "Downstream Elevation (ft)",       "3708.00"
"English",    "Width's A Term (s/ft²)",         "14.400"
"English",    "  B Term where W = A*Q**B",       "0.110"
"English",    "Manning's n",                  "0.036"
"English",    "Air Temperature (°F)",          "78.400"
"English",    "Relative Humidity (%)",          "32.800"
"English",    "Wind Speed (mph)",              "7.100"
"English",    "Ground Temperature (°F)",        "55.000"
"English",    "Thermal gradient (j/m²/s/C)",     "1.650"
"English",    "Possible Sun (%)",             "90.000"
"English",    "Dust Coefficient",             "5.000"
"English",    "Ground Reflectivity (%)",         "25.000"
"English",    "Solar Radiation (Langleys/d)",    "630.897"
"English",    "Total Shade (%)",              "8.194"
"English",    "Segment Azimuth (degrees)",       "-45.000"
"West Side Variables"
"English",    "Topographic Altitude (degrees)",  "6.000"
"English",    "Vegetation Height (ft)",         "15.000"
"English",    "Vegetation Crown (ft)",          "10.000"
"English",    "Vegetation Offset (ft)",         "5.000"
"English",    "Vegetation Density (%)",         "15.000"
"East Side Variables"
"English",    "Segment Azimuth (degrees)",       "6.000"
"English",    "Topographic Altitude (degrees)",  "10.000"
"English",    "Vegetation Height (ft)",         "10.000"
"English",    "Vegetation Crown (ft)",          "10.000"
"English",    "Vegetation Offset (ft)",         "30.000"
"English",    " Maximum Air Temp (°F)",         "83.382"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
     "Predicted Mean (°F) = 69.71"
     "Estimated Maximum (°F) = 78.64"
```

```
        "Approximate Minimum (°F) = 60.79"
        "Mean Equilibrium (°F) = 73.39"
        "Maximum Equilibrium (°F) = 83.03"
        "Minimum Equilibrium (°F) = 63.75"
```

Segment 5a, Prickly Pear Segment MT411006_020 to Sierra Road

Current conditions

```
"English",      "Segment Inflow (cfs)",           "1.500"
"English",      "Inflow Temperature (°F)",         "59.700"
"English",      "Segment Outflow (cfs)",           "7.500"
"English",      "Accretion Temp. (°F)",           "53.000"
"English",      "Latitude (degrees)",            "46.650"
"English",      "Segment Length (mi)",             "3.030"
"English",      "Upstream Elevation (ft)",         "3708.00"
"English",      "Downstream Elevation (ft)",        "3677.00"
"English",      "Width's A Term (s/ft²)",         "14.800"
"English",      "  B Term where W = A*Q**B",      "0.150"
"English",      "Manning's n",                  "0.035"
"English",      "Air Temperature (°F)",           "78.740"
"English",      "Relative Humidity (%)",           "32.400"
"English",      "Wind Speed (mph)",               "7.100"
"English",      "Ground Temperature (°F)",         "55.000"
"English",      "Thermal gradient (j/m²/s/C)",     "1.650"
"English",      "Possible Sun (%)",              "90.000"
"English",      "Dust Coefficient",             "5.000"
"English",      "Ground Reflectivity (%)",         "25.000"
"English",      "Solar Radiation (Langleys/d)",    "630.649"
"English",      "Total Shade (%)",               "5.819"
"English",      "Segment Azimuth (degrees)",       "40.000"
"West Side Variables"
"English",      "Topographic Altitude (degrees)",  "6.000"
"English",      "Vegetation Height (ft)",         "5.000"
"English",      "Vegetation Crown (ft)",          "15.000"
"English",      "Vegetation Offset (ft)",         "5.000"
"English",      "Vegetation Density (%)",          "20.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",       "4.000"
"English",      "Topographic Altitude (degrees)",  "10.000"
"English",      "Vegetation Height (ft)",         "10.000"
"English",      "Vegetation Crown (ft)",          "5.000"
"English",      "Vegetation Offset (ft)",         "10.000"
"English",      " Maximum Air Temp (°F)",          "83.734"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
        "Predicted Mean (°F) = 65.04"
        "Estimated Maximum (°F) = 77.18"
```

```
    "Approximate Minimum (°F) = 52.91"
    "Mean Equilibrium (°F) = 73.56"
    "Maximum Equilibrium (°F) = 83.35"
    "Minimum Equilibrium (°F) = 63.77"

Sensitivity for mean temperature values (10% variation)    SSTEMP (2.0.8)
Original mean temperature = 65.04°F
                          Temperature change (°F)
                            if variable is:
Variable                   Decreased Increased   Relative Sensitivity
--------------------------------------------------------------------------------
Segment Inflow (cfs)          -0.11    +0.11 *
Inflow Temperature (°F)        -0.12    +0.14 *
Segment Outflow (cfs)          +0.52    -0.58 *****
Accretion Temp. (°F)          -2.12    +2.12 ******************
Width's A Term (s/ft²)        -0.52    +0.58 *****
  B Term where W = A*Q**B         -0.12    +0.12 *
Manning's n                +0.00    +0.00
Air Temperature (°F)          -3.39    +3.02 *****************************
Relative Humidity (%)          -0.53    +0.54 *****
Wind Speed (mph)              +0.14    -0.15 *
Ground Temperature (°F)         -0.17    +0.17 *
Thermal gradient (j/m²/s/C)     +0.03    -0.03
Possible Sun (%)             -0.30    +0.42 ****
Dust Coefficient             +0.02    -0.02
Ground Reflectivity (%)        -0.03    +0.03
Segment Azimuth (degrees)       -0.01    +0.01
West Side:
Topographic Altitude (degrees)  +0.00     0.00
Vegetation Height (ft)         +0.01    -0.01
Vegetation Crown (ft)          +0.02    -0.02
Vegetation Offset (ft)        -0.01    +0.01
Vegetation Density (%)          +0.02    -0.02
East Side:
Topographic Altitude (degrees)  +0.00     0.00
Vegetation Height (ft)         +0.02    -0.02
Vegetation Crown (ft)          +0.01    -0.01
Vegetation Offset (ft)        -0.01    +0.01
Vegetation Density (%)          +0.02    -0.02
```

Segment 5b, Prickly Pear Segment MT41I006_020

Current conditions

```
"English",    "Segment Inflow (cfs)",        "1.500"
"English",    "Inflow Temperature (°F)",      "59.700"
"English",    "Segment Outflow (cfs)",        "16.500"
"English",    "Accretion Temp. (°F)",        "55.000"
"English",    "Latitude (degrees)",        "46.660"
"English",    "Segment Length (mi)",         "6.830"
"English",    "Upstream Elevation (ft)",      "3708.00"
```

```
"English",      "Downstream Elevation (ft)",      "3650.00"
"English",      "Width's A Term (s/ft²)",        "15.000"
"English",      "  B Term where W = A*Q**B",       "0.190"
"English",      "Manning's n",                 "0.034"
"English",      "Air Temperature (°F)",          "78.740"
"English",      "Relative Humidity (%)",          "32.400"
"English",      "Wind Speed (mph)",              "7.100"
"English",      "Ground Temperature (°F)",        "55.000"
"English",      "Thermal gradient (j/m²/s/C)",    "1.650"
"English",      "Possible Sun (%)",             "90.000"
"English",      "Dust Coefficient",             "5.000"
"English",      "Ground Reflectivity (%)",        "25.000"
"English",      "Solar Radiation (Langleys/d)",   "630.578"
"English",      "Total Shade (%)",              "7.040"
"English",      "Segment Azimuth (degrees)",       "30.000"
"West Side Variables"
"English",      "Topographic Altitude (degrees)",  "6.000"
"English",      "Vegetation Height (ft)",         "5.000"
"English",      "Vegetation Crown (ft)",          "10.000"
"English",      "Vegetation Offset (ft)",         "10.000"
"English",      "Vegetation Density (%)",         "15.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",       "4.000"
"English",      "Topographic Altitude (degrees)",  "10.000"
"English",      "Vegetation Height (ft)",         "10.000"
"English",      "Vegetation Crown (ft)",          "5.000"
"English",      "Vegetation Offset (ft)",         "25.000"
"English",      " Maximum Air Temp (°F)",         "83.734"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
      "Predicted Mean (°F) = 66.31"
      "Estimated Maximum (°F) = 76.03"
      "Approximate Minimum (°F) = 56.59"
      "Mean Equilibrium (°F) = 73.42"
      "Maximum Equilibrium (°F) = 83.14"
      "Minimum Equilibrium (°F) = 63.70"

Sensitivity for mean temperature values (10% variation)    SSTEMP (2.0.8)
Original mean temperature = 66.31°F
                         Temperature change (°F)
                           if variable is:
Variable                  Decreased Increased   Relative Sensitivity
-------------------------------------------------------------------------------
Segment Inflow (cfs)          -0.05    +0.05
Inflow Temperature (°F)        -0.02    +0.02
Segment Outflow (cfs)          +0.38    -0.41 ****
Accretion Temp. (°F)          -2.11    +2.11 ******************
Width's A Term (s/ft²)        -0.45    +0.51 ****
```

```
 B Term where W = A*Q**B       -0.20    +0.20 **
Manning's n                +0.00    +0.00
Air Temperature (°F)           -3.47    +3.13 ******************************
Relative Humidity (%)          -0.54    +0.55 *****
Wind Speed (mph)               +0.18    -0.19 **
Ground Temperature (°F)        -0.17    +0.17 *
Thermal gradient (j/m²/s/C)    +0.04    -0.04
Possible Sun (%)            -0.30    +0.42 ****
Dust Coefficient            +0.02    -0.02
Ground Reflectivity (%)        -0.03    +0.03
Segment Azimuth (degrees)       0.00     0.00
West Side:
Topographic Altitude (degrees)   +0.01     0.00
Vegetation Height (ft)          +0.01    -0.01
Vegetation Crown (ft)           +0.00     0.00
Vegetation Offset (ft)          -0.01    +0.01
Vegetation Density (%)           +0.00     0.00
East Side:
Topographic Altitude (degrees)   +0.00     0.00
Vegetation Height (ft)          +0.04    -0.04
Vegetation Crown (ft)           +0.02    -0.02
Vegetation Offset (ft)          -0.02    +0.02
Vegetation Density (%)           +0.05    -0.05
```

Natural conditions

```
"English",     "Segment Inflow (cfs)",          "21.300"
"English",     "Inflow Temperature (°F)",        "67.670"
"English",     "Segment Outflow (cfs)",          "36.300"
"English",     "Accretion Temp. (°F)",          "55.000"
"English",     "Latitude (degrees)",           "46.660"
"English",     "Segment Length (mi)",           "6.830"
"English",     "Upstream Elevation (ft)",        "3708.00"
"English",     "Downstream Elevation (ft)",       "3650.00"
"English",     "Width's A Term (s/ft²)",         "15.000"
"English",     "  B Term where W = A*Q**B",       "0.190"
"English",     "Manning's n",               "0.034"
"English",     "Air Temperature (°F)",          "78.740"
"English",     "Relative Humidity (%)",          "32.400"
"English",     "Wind Speed (mph)",             "7.100"
"English",     "Ground Temperature (°F)",         "55.000"
"English",     "Thermal gradient (j/m²/s/C)",     "1.650"
"English",     "Possible Sun (%)",             "90.000"
"English",     "Dust Coefficient",             "5.000"
"English",     "Ground Reflectivity (%)",         "25.000"
"English",     "Solar Radiation (Langleys/d)",     "630.578"
"English",     "Total Shade (%)",              "30.302"
"English",     "Segment Azimuth (degrees)",       "30.000"
"West Side Variables"
"English",     "Topographic Altitude (degrees)", "10.000"
"English",     "Vegetation Height (ft)",         "25.000"
```

```
"English",      "Vegetation Crown (ft)",        "10.000"
"English",      "Vegetation Offset (ft)",       "5.000"
"English",      "Vegetation Density (%)",        "50.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",      "10.000"
"English",      "Topographic Altitude (degrees)", "15.000"
"English",      "Vegetation Height (ft)",        "10.000"
"English",      "Vegetation Crown (ft)",         "2.000"
"English",      "Vegetation Offset (ft)",       "55.000"
"English",      " Maximum Air Temp (°F)",         "83.734"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
     "Predicted Mean (°F) = 65.82"
     "Estimated Maximum (°F) = 71.98"
     "Approximate Minimum (°F) = 59.66"
     "Mean Equilibrium (°F) = 70.80"
     "Maximum Equilibrium (°F) = 79.10"
     "Minimum Equilibrium (°F) = 62.50"
```

Restoration 9. Increase vegetation density under current flow

```
"English",      "Segment Inflow (cfs)",         "1.500"
"English",      "Inflow Temperature (°F)",        "59.700"
"English",      "Segment Outflow (cfs)",          "16.500"
"English",      "Accretion Temp. (°F)",          "55.000"
"English",      "Latitude (degrees)",           "46.660"
"English",      "Segment Length (mi)",            "6.830"
"English",      "Upstream Elevation (ft)",        "3708.00"
"English",      "Downstream Elevation (ft)",       "3650.00"
"English",      "Width's A Term (s/ft²)",        "15.000"
"English",      "  B Term where W = A*Q**B",       "0.190"
"English",      "Manning's n",                 "0.034"
"English",      "Air Temperature (°F)",          "78.740"
"English",      "Relative Humidity (%)",          "32.400"
"English",      "Wind Speed (mph)",              "7.100"
"English",      "Ground Temperature (°F)",         "55.000"
"English",      "Thermal gradient (j/m²/s/C)",     "1.650"
"English",      "Possible Sun (%)",              "90.000"
"English",      "Dust Coefficient",             "5.000"
"English",      "Ground Reflectivity (%)",        "25.000"
"English",      "Solar Radiation (Langleys/d)",    "630.578"
"English",      "Total Shade (%)",              "34.466"
"English",      "Segment Azimuth (degrees)",       "30.000"
"West Side Variables"
"English",      "Topographic Altitude (degrees)", "10.000"
"English",      "Vegetation Height (ft)",        "25.000"
"English",      "Vegetation Crown (ft)",         "10.000"
"English",      "Vegetation Offset (ft)",       "5.000"
```

```
"English",      "Vegetation Density (%)",       "50.000"
"East Side Variables"
"English",      "Segment Azimuth (degrees)",      "10.000"
"English",      "Topographic Altitude (degrees)", "15.000"
"English",      "Vegetation Height (ft)",       "10.000"
"English",      "Vegetation Crown (ft)",         "2.000"
"English",      "Vegetation Offset (ft)",       "55.000"
"English",      " Maximum Air Temp (°F)",         "83.734"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
        "Predicted Mean (°F) = 64.12"
        "Estimated Maximum (°F) = 71.50"
        "Approximate Minimum (°F) = 56.74"
        "Mean Equilibrium (°F) = 70.25"
        "Maximum Equilibrium (°F) = 78.28"
        "Minimum Equilibrium (°F) = 62.22"
```

Restoration 10. Inflow from restoration 8 in segment MT41I006 030

```
"English",      "Segment Inflow (cfs)",         "21.300"
"English",      "Inflow Temperature (°F)",        "69.710"
"English",      "Segment Outflow (cfs)",          "36.300"
"English",      "Accretion Temp. (°F)",          "55.000"
"English",      "Latitude (degrees)",          "46.660"
"English",      "Segment Length (mi)",            "6.830"
"English",      "Upstream Elevation (ft)",        "3708.00"
"English",      "Downstream Elevation (ft)",       "3650.00"
"English",      "Width's A Term (s/ft²)",         "15.000"
"English",      "  B Term where W = A*Q**B",       "0.190"
"English",      "Manning's n",                  "0.034"
"English",      "Air Temperature (°F)",          "78.740"
"English",      "Relative Humidity (%)",          "32.400"
"English",      "Wind Speed (mph)",               "7.100"
"English",      "Ground Temperature (°F)",         "55.000"
"English",      "Thermal gradient (j/m²/s/C)",     "1.650"
"English",      "Possible Sun (%)",             "90.000"
"English",      "Dust Coefficient",             "5.000"
"English",      "Ground Reflectivity (%)",        "25.000"
"English",      "Solar Radiation (Langleys/d)",    "630.578"
"English",      "Total Shade (%)",              "5.910"
"English",      "Segment Azimuth (degrees)",       "30.000"
"West Side Variables"
"English",      "Topographic Altitude (degrees)", "6.000"
"English",      "Vegetation Height (ft)",        "5.000"
"English",      "Vegetation Crown (ft)",          "10.000"
"English",      "Vegetation Offset (ft)",       "10.000"
"English",      "Vegetation Density (%)",         "15.000"
"East Side Variables"
```

```
"English",      "Segment Azimuth (degrees)",      "4.000"
"English",      "Topographic Altitude (degrees)",  "10.000"
"English",      "Vegetation Height (ft)",        "10.000"
"English",      "Vegetation Crown (ft)",          "5.000"
"English",      "Vegetation Offset (ft)",        "25.000"
"English",      " Maximum Air Temp (°F)",          "83.734"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/07"
     "Predicted Mean (°F) = 67.86"
     "Estimated Maximum (°F) = 75.72"
     "Approximate Minimum (°F) = 59.99"
     "Mean Equilibrium (°F) = 73.59"
     "Maximum Equilibrium (°F) = 83.37"
     "Minimum Equilibrium (°F) = 63.82"
```

Appendix H

Supplemental Monitoring and Assessment Strategy

Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report

August 31, 2006

Prepared for the Montana Department of Environmental Quality

Prepared by the U.S. Environmental Protection Agency,
Montana Operations Office
With Technical Support from Tetra Tech, Inc.
and PBS&J, Inc.

Project Manager: Ron Steg

Contents

1.0 INTRODUCTION ... 1
2.0 DATA GAPS MONITORING AND ASSESSMENT ... 3
- 2.1 Watershed Hydrology and Groundwater/Surface Water Interactions ... 4
- 2.2 In-stream Nutrient Target Setting and Source Assessment ... 5
  - 2.2.1 Hydraulic Studies ... 5
  - 2.2.2 General Water Quality Characterization ... 5
  - 2.2.3 Dissolved Oxygen Sag Point Analysis ... 6
  - 2.2.4 Detailed Water Quality Characterization (Intensive Survey) ... 6
  - 2.2.5 Nutrient Source Assessment Monitoring ... 7
- 2.3 Lake Helena and Hauser Reservoir Nutrient Dynamics and Target Setting ... 8
- 2.4 Metals Monitoring Strategy ... 10
  - 2.4.1 Addressing Metals Impairment Uncertainties ... 10
  - 2.4.2 Refinement of Metals Sources and Seasonality ... 11
  - 2.4.3 Addressing Modeling Uncertainties ... 11
- 2.5 Temperature Monitoring Strategy ... 12
  - 2.5.1 Addressing Temperature Impairment Uncertainties ... 12
  - 2.5.2 Refinement of Temperature Impairment Causes ... 12
- 2.6 Modeling Tool Development ... 14

3.0 IMPLEMENTATION MONITORING ... 15
4.0 EFFECTIVENESS MONITORING AND ADAPTIVE MANAGEMENT ... 17
5.0 SAMPLING AND ANALYSIS METHODS AND QUALITY ASSURANCE CONSIDERATIONS ... 19

Tables

Table 2-1. Prickly Pear Creek nutrient/DO intensive survey parameter list. 7
Table 2-2. Proposed Lake Helena and Hauser Reservoir nutrient monitoring stations. 8
Table 2-3. Proposed Lake Helena inflow monitoring stations. 10
Table 2-4. Lake Helena watershed segments requiring impairment status confirmation. 11
Table 2-5. Point source discharge temperature monitoring stations for lower Prickly Pear Creek. 12
Table 4-1. Active NOAA climate stations in the Lake Helena Watershed. 18

1.0 INTRODUCTION

This supplemental monitoring and assessment strategy presents an overview of future monitoring needs in the Lake Helena watershed that have been identified during the development of the draft water quality restoration plan and TMDLs. The monitoring strategy is described in general terms at this time, and a more detailed Sampling and Analysis Plan (SAP) should be developed during the implementation phase of the TMDL. Focused monitoring and assessment efforts are needed to fulfill three primary goals:

- Obtain additional data to address information gaps and uncertainty in the current analysis (data gaps monitoring and assessment)
- Ensure that identified management actions are undertaken (implementation monitoring)
- Ensure that management actions are having the desired effect (effectiveness monitoring)

Data gaps monitoring and assessment needs are described in Section 2.0, and implementation and effectiveness monitoring are presented in Sections 3.0 and 4.0, respectively. Specific sampling and analysis methods are described in more detail in Section 5.0.

2.0 DATA GAPS MONITORING AND ASSESSMENT

Monitoring to fill data gaps and improve certainty in the assumptions applied within the Lake Helena water quality restoration plan is the highest priority because these data are needed to confirm the appropriateness of specific restoration measures. For example, only interim nutrient targets have been established for the streams in the Lake Helena watershed due to uncertainties associated with specific impairment thresholds, as well as the technical and economic feasibility of attaining the proposed in-stream targets. Similarly, nutrient targets have not yet been selected for Lake Helena due to limited water quality data and an incomplete understanding of the inter-relationships between Lake Helena and Hauser Reservoir. Limited recent data have also precluded a complete understanding of metals and temperature impairments for some stream segments. Additional monitoring and assessment is therefore needed to address these and other data gaps and should include the following:

- *Watershed Hydrology and Groundwater/Surface Water Interactions* - Additional investigation is needed to more fully understand surface water/groundwater inter-relationships in the Lake Helena watershed and to discern the effects of various water management practices on surface water quality. Specific needs include a water balance study for the Helena Valley portion of the watershed to examine the effects of inter-basin transfers (Missouri River via the Helena Valley Irrigation District), surface water withdrawals, storm water and wastewater discharges, gains and losses from groundwater, and flow reversal from Hauser Reservoir to Lake Helena. A focused study is also needed to evaluate natural and artificial sources of groundwater recharge in the Helena Valley, including canal losses, storm water discharges, individual and community septic systems, irrigated fields, and their implications to ground and surface water quality.

- *In-stream Nutrient Target Setting and Source Assessment* - Additional monitoring is needed to understand the relationships between in-stream nutrient concentrations and beneficial use impairments in the Prickly Pear and Tenmile Creek drainages. Furthermore, some data gaps remain with regard to identifying specific sources of nutrient loading, particularly in lower Prickly Pear Creek.

- *Lake Helena and Hauser Reservoir Nutrient Dynamics and Target Setting* – Recent water quality and limnological data for Lake Helena and the Causeway Arm of Hauser Reservoir are extremely limited. Seasonal, multi-year data are needed to more fully document present conditions, to refine a nutrient loading/lake response model, to understand water quality and hydrologic relationships between Lake Helena and Hauser Reservoir, and to provide a basis for nutrient target setting.

- *Metals Impairment Confirmation and Source Assessment* - Additional metals data are needed for some segments to confirm and define suspected impairments, and to help characterize the magnitude and seasonality of contributing source areas.

- *Temperature* – Factors contributing to temperature impairments in Prickly Pear Creek are not well understood due to limited data. Specifically, the influences of irrigation water withdrawals, groundwater/surface water interactions, wastewater discharges, riparian vegetation, and stream channel characteristics should be further quantified in order to allow fine-tuning of restoration prescriptions.

- *Modeling Tool Development* – The Lake Helena restoration plan recommends the development of modeling tools to help predict the water quality consequences of land use changes and various management measures (see Section 3.2.3.2 of Volume II). Additional data collection is recommended to support recalibration and fine-tuning of the existing watershed-scale nutrient loading and lake response models.

Plans for addressing each of these primary data deficiencies are described in more detail in the following paragraphs.

2.1 Watershed Hydrology and Groundwater/Surface Water Interactions

The hydrology of the Lake Helena watershed is relatively complex and is further complicated by intensive land and water management. Preliminary analyses have shown that the hydrology of the lower watershed is heavily influenced by the seasonal importation of Missouri River water via the Helena Valley Regulating Reservoir and the Helena Valley Irrigation Canal. Some of this imported water is directly discharged back to Lake Helena in the form of canal surplus water or irrigation return flows. Other portions enter the valley groundwater system through canal losses and from irrigated fields. At the same time, the lower reaches of Prickly Pear and Tenmile Creeks are seasonally dewatered because of irrigation, while Prickly Pear Creek is the receiving water body for several wastewater discharges. Hundreds of individual septic systems, storm water outfalls, canals and ditches, and irrigated fields discharge water to the Helena Valley aquifer, and an extensive network of tile drains throughout the valley artificially lowers the elevation of the shallow groundwater and discharges the drainage directly to Lake Helena. To further complicate matters, evidence suggests that where Lake Helena discharges to Hauser Reservoir at the Lake Helena Causeway, flow direction sometimes reverses depending upon the operation of Hauser Dam and/or the magnitude of local storm/runoff events. Understanding how water moves through the watershed on a seasonal and annual basis, and how groundwater and surface waters interact, is a critical first step in managing for improved water quality.

This study element would establish a water balance for the Helena Valley portion of the Lake Helena watershed. A comprehensive flow gaging network would be established on lower Prickly Pear and Tenmile creeks, in various canals and ditches, and at the Lake Helena Causeway. Irrigation diversions and wastewater discharges would also be monitored, either directly or through permit and water rights records. A series of flow recorders (Aquarods) would be installed at strategic locations and surface flows would be gaged periodically over the course of several years representing wet and dry conditions. The temporal and spatial extent of stream dewatering and points of irrigation withdrawal would be documented. An additional study element would evaluate and quantify the potential water quality benefits that could accrue from supplementing chronically low summer stream flows in lower Prickly Pear and Tenmile Creeks. We will also support the Lewis and Clark County Water Quality Protection District's continuing efforts to fund and initiate a groundwater monitoring program in the Helena Valley for purposes of identifying and quantifying sources of recharge and to help define groundwater/surface water interactions. The ultimate goal of this monitoring element is to improve our understanding of basin hydrology and to provide a basis for fine-tuning watershed models and predictive capabilities.

2.2 In-stream Nutrient Target Setting and Source Assessment

To better understand the relationship between in-stream nutrient concentrations, benthic algae, and dissolved oxygen (DO) levels in lower Prickly Pear Creek, water quality data should be collected to support the development of a more refined water quality model. Options include using the existing LSPC modeling framework (i.e., using/refining the LSPC model that has been set up for the metals analysis) or a steady-state dissolved oxygen model such as QUAL2K. Setting up and calibrating nutrient/DO models typically require data that describe physical channel characteristics and in-stream processes that control DO concentrations. Two intensive water quality surveys and two hydraulic studies (transect measurements and dye studies) are proposed during two different flow/temperature conditions in order to provide the necessary data. Proposed monitoring stations are listed below and study elements are described in the paragraphs that follow:

- City of Helena wastewater treatment plant (WWTP) effluent ditch at confluence with Prickly Pear Creek
- Prickly Pear Creek immediately upstream of City of Helena WWTP
- Prickly Pear Creek immediately downstream of City of Helena WWTP
- Prickly Pear Creek below confluence with Tenmile Creek
- Prickly Pear Creek at Lake Helena

2.2.1 Hydraulic Studies

Hydraulic studies are required to estimate the velocity of Prickly Pear Creek throughout the study area. Physical channel measurements (cross sections and longitudinal profiles) should be performed at transects throughout the study area to determine the physical channel dimensions. Additionally, dye studies should be performed to estimate stream velocities for use in the estimation of flow/velocity relationships and prediction of travel times. Distribution of dye concentrations will help calculate longitudinal dispersion while peak-to-peak time will support velocity estimates. Two separate dye sampling events should be performed to estimate the velocities under two flow regimes (snowmelt runoff and summer low flow). The timing of these studies would require that no significant rainfall events (> 0.5 inches) have occurred in the previous seven days, and the creek has reached steady state flows during the sampling period. Daily flow measurements should also be recorded for Tenmile and Prickly Pear creeks during the studies.

2.2.2 General Water Quality Characterization

Field sampling for general water quality parameters (temperature, pH, conductivity, DO, streamflow) should be performed at all transect locations, intensive survey sites, and at the mouth of significant tributaries to Prickly Pear Creek. Sampling will be performed using handheld instruments and all pertinent data will be recorded in a field log. Data from this sampling effort would be used to characterize the overall water quality in the study area and to identify changes in water quality that would indicate previously unidentified pollutant sources. Streambed descriptions of channel roughness, available area for plant growth (%), sediment thickness, percent sediment/silt coverage, and percent cloud cover and shade cover should also be recorded.

2.2.3 Dissolved Oxygen Sag Point Analysis

The point in a stream below a wastewater discharge where in-stream dissolved oxygen concentrations reach their lowest level is referred to as the DO sag point. Field measurements can be used to identify the location of the sag point and to determine the distance required for the dissolved concentrations to return to ambient levels. Field results for general water quality parameters should be collected at several locations (approximately every 250 meters) in the section of Prickly Pear Creek between the City of Helena wastewater outfall and the Tenmile Creek confluence. These data would be used to support the model calibration/validation efforts and would provide a basis for assessing model accuracy for critical in-stream locations.

2.2.4 Detailed Water Quality Characterization (Intensive Survey)

Detailed intensive surveys are required to gain a more complete understanding of water quality conditions in Prickly Pear Creek. These surveys would combine field observations with the collection of water samples for analysis of parameters such as ammonia and biological oxygen demand in order to characterize the effects of oxygen demanding wastes. Two separate intensive sampling events are recommended to provide a detailed understanding of in-stream water quality. As with the hydrologic studies, timing would require that no significant rainfall events (> 0.5 inches) have occurred in the previous seven days, and that the creek has reached steady state flows during the sampling period.

Sediment samples should also be collected for analysis. These samples will be analyzed for sediment composition (sand, silt, and clay fractions) and total organic content for comparison with the sediment oxygen demand component in the model.

The intensive surveys should consist of field measurements as well as the collection of water quality samples for lab analysis (Table 2-1). Field measurements would include the same general water quality monitoring to be performed at the transect locations as well as diel (24-hour) monitoring of DO at a location near the observed maximum in-stream sag. This diel survey would be used to characterize the rates and extent of DO and pH fluctuations downstream of the City of Helena wastewater outfall.

Table 2-1. Prickly Pear Creek nutrient/DO intensive survey parameter list.

Variable	Number of Surveys	Sampling Frequency	Sampling Locations
Temperature	2	4/Day	All
Dissolved Oxygen	2	4/Day	All (plus diel study)
Conductivity	2	4/Day	All
pH	2	4/Day	All
Sediment Composition	2	1/Day	All
$CBOD_5$ (Filtered)	2	4/Day	All
$CBOD_5$ (Unfiltered)	2	2/Day	All
$CBOD_{20}$ (Filtered)	2	4/Day	All
$CBOD_{20}$ (Unfiltered)	2	2/Day	All
BOD_{20}	2	2/Day	All
Kjeldahl-N	2	2/Day	All
NH_3	2	4/Day	All
NO_3	2	4/Day	All
NO_2	2	2/Day	All
TSS	2	2/Day	All
VSS	2	2/Day	All
TOC	2	4/Day	All
Total Phosphorus	2	2/Day	All
Orthophosphorus	2	2/Day	All
Macrophytes	2	2/Day	All
Benthic Chlorophyll a	2	2/Day	All

2.2.5 Nutrient Source Assessment Monitoring

Existing monitoring data that can be used to identify specific nutrient sources in lower Prickly Pear Creek are limited. In many cases, monitoring stations bracketed long reaches of the creek and assumptions have been made about the nature of sources that are likely to be present between these stations. The City of Helena wastewater has traditionally been used to irrigate hay fields located to the west of Prickly Pear Creek during much of the summer season. As such, direct discharges to Prickly Pear Creek occur intermittently and at variable rates. Additionally, Prickly Pear Creek through its lower reaches receives tile drainage and groundwater discharge, and adjacent lands sustain a variety of uses that may contribute nutrients to the creek.

Synoptic surveys should be performed on a quarterly basis at a series of stations beginning at the Wylie Drive crossing just north of East Helena and continuing to Lake Helena. The surveys would document sequential nutrient loading from all sources through this segment of the creek during multiple seasons and under a range of streamflow conditions. All surface discharges and water withdrawals will be monitored to account for gains and losses of nitrogen and phosphorus loading. Groundwater contributions (or losses to groundwater) will also be accounted for. The City of Helena's wastewater would be monitored for nutrient content and flow rates at the facility and at the point of discharge to Prickly Pear Creek, and irrigation usage and volumes would be recorded. Collectively, the data will be used to establish a nutrient loading budget and source quantification for each of the synoptic sampling events. The study results would be used to adjust the nutrient allocations and control strategy for Prickly Pear Creek, if warranted.

2.3 Lake Helena and Hauser Reservoir Nutrient Dynamics and Target Setting

Available data that can be used to describe the trophic status and trends in Lake Helena and Hauser Reservoir are extremely limited. A concerted monitoring program is needed to confirm the degree of nutrient impairment that may be present, to provide a basis for nutrient target setting, and to understand how discharged water from how Lake Helena affects water quality and beneficial uses in Hauser Reservoir. Furthermore, because Lake Helena is a manmade water body with unusual hydraulic and water quality characteristics, it may prove to be more appropriate to set nutrient targets for the Causeway Arm of Hauser Reservoir instead of for Lake Helena proper. Lastly, a nutrient TMDL and restoration plan will eventually need to be developed for Hauser Reservoir and the Missouri River, and it is important that restoration strategies for Lake Helena watershed are consistent with those developed for downstream water bodies.

In addition to the hydrologic investigations and water quality modeling studies that are described in other sections of this appendix, we propose to undertake a concerted three-year limnological and water quality study of Lake Helena and Hauser Reservoir together with selected inflows. A series of nine fixed reservoir stations, shown in Table 2-2 below, should be monitored on a monthly or more frequent basis.

Table 2-2. Proposed Lake Helena and Hauser Reservoir nutrient monitoring stations.

Waterbody	Site ID	Site Type	Description	Lat	Long
Lake Helena	M09LHLNO01	Historic	Lake Helena PPL Inlet Station, 150 yards off FWP boat access off mouth of Silver Creek	46.69869	111.95731
	M09LHLN101	Historic	Lake Helena PPL Outlet Station, Lake Helena side of the causeway	46.70259	111.9014
	M09LHLNC01	Historic	EPA/FWP # 2 middle of the lake/deep station	46.69678	111.9178
	M09LHLNE01	Historic	EPA/FWP Lake Helena Deep Station	46.69875	111.9013
Causeway Arm	C3	Historic	BOR Causeway Station, downstream of Lake Helena	46. 70432	111.90142
	C2	Historic	BOR Causeway Station in middle of the Causeway Arm	46.71839	111.87737
	C1	Historic	BOR Causeway Station, near mouth of Hauser Reservoir	46.73539	111.89065
Hauser Reservoir	HA4	Historic	BOR, Upstream of Causeway Inflow Station	46.73549	111.87840
	HA5	Historic	BOR, Montana Fish, Wildlife and Parks Buoy at Dam	46.76302	111.88460

Recommended reservoir monitoring variables include total water depth, water temperature, pH, alkalinity, specific conductance, turbidity, total suspended sediment, Secchi depth, chlorophyll *a*, the full complement of nutrient variables, total recoverable metals (arsenic and lead), and dissolved oxygen. Water samples should be taken at three different depths at each sample location: 0.5 meters below the surface, at mid-depth, and one meter from the bottom. The chlorophyll samples should be collected as a composite from throughout the euphotic zone. Field parameters (temperature, dissolved oxygen, pH, and conductivity) should be measured 0.5 meters below the surface and at one meter intervals throughout the water column.

Once annually, bottom sediment samples should be collected for analysis of metals concentrations (see Section 2.5 below). During summer, samples should be collected for identification and relative quantification of resident phytoplankton algae, and the occurrence of any algae blooms should be noted. Missouri River sampling locations should include all of the above sampling variables except for Secchi depth, chlorophyll *a*, DO depth profiles, sediment quality, and phytoplankton.

Synoptic monitoring would be conducted in the inflows to Lake Helena, including Prickly Pear, Tenmile and Silver creeks, as well as tile drains and irrigation waterways. Monitoring would be timed to coincide with spring runoff, summer storm events, and baseflow conditions to further refine the understanding of potential nutrient, sediment, and metals sources. The proposed tributary monitoring sites and main irrigation drains are shown in Table 2-3.

Grab water samples would be analyzed for the following field and laboratory parameters:

- *Field Parameters* – Temperature, stream flow, pH, dissolved oxygen, turbidity.
- *Laboratory Parameters* – the full complement of nutrient variables, total suspended solids (TSS), hardness, and total recoverable metals (arsenic, cadmium, copper, lead, and zinc).

The Lake Helena inflow monitoring should be closely coordinated with water quality and hydrology monitoring activities described in Sections 2.1 and 2.2 of this appendix.

Table 2-3. Proposed Lake Helena inflow monitoring stations.

Waterbody	Site ID	Site Type	Description	Lat	Long
Tributary Streams	M09SLRC01	Historic	Silver Creek downstream of frontage road	46.67638800	112.01055500
	USGS 06064150	Historic	Tenmile Creek above Prickly Pear Creek near Helena	46.66076917	111.98999560
	USGS 463939111582801	Historic	Prickly Pear Creek above Tenmile Creek near East Helena	46.66076940	111.97527250
Irrigation Ditches	M09SCIDC01	Historic	Silver Creek Ditch, near mouth above Lake Helena	46. 6928000	111.9721
	M09HVIFD01	Historic	Helena Valley Field Drain, near mouth near Valley Drive	46.6848000	111.91010000
	M09HVIFD02	Historic	Helena Valley Field Drain, near mouth @ Helberg Lane	46.6798000	111.9463000

Reservoir and inflow monitoring data would be interpreted annually and combined with the results of the hydrologic investigations and modeling efforts to refine nutrient targets and source allocations for Lake Helena and/or Hauser Reservoir. Water column and sediment metals and turbidity data will be used to reevaluate/confirm suspected metals and sediment impairments in Lake Helena and its inflows.

2.4 Metals Monitoring Strategy

Future metals monitoring in the Lake Helena watershed to address existing data gaps should address the following objectives:

- Uncertainties associated with impairment determinations
- Refinement of metals sources and seasonality
- Uncertainties associated with the modeling process

Each of these objectives is detailed below.

2.4.1 Addressing Metals Impairment Uncertainties

Table 2-4 identifies stream segments in the Lake Helena watershed with limited metals data. These segments should be sampled a minimum of 5 to 10 times each over a representative time period which includes wet, dry and normal precipitation years in order to better determine impairment status. Samples should be taken during both base flow periods and during episodic storm events. Data would be used be used to confirm suspected impairment issues and to refine TMDLs and source allocations. The data would also be used to determine if a TMDL is required for mercury in Silver Creek.

Table 2-4. Lake Helena watershed segments requiring impairment status confirmation.

Segment	Reason for Additional Monitoring
Prickly Pear Creek from the Headwaters to Spring Creek (MT41I006_060)	Borderline levels of cadmium and copper
Prickly Pear Creek from Spring Creek to Lump Gulch (MT41I006_050)	Borderline levels of arsenic and copper
Prickly Pear Creek from Wylie Drive to Helena Wastewater Treatment Plant Discharge (MT41I006_030)	Limited data
Prickly Pear Creek from Helena WWTP Discharge Ditch to Lake Helena (MT41I006_020)	Limited data
Golconda Creek from the Headwaters to the Mouth (MT41I006_070)	Limited data; borderline levels of zinc
Corbin Creek from the Headwaters to the Mouth (MT41I006_090)	Limited data for current conditions
Spring Creek from Corbin Creek to the Mouth (MT41I006_080)	Limited data
North Fork Warm Springs Creek from the Headwaters to the Mouth (MT41I006_180)	Borderline levels of lead
Skelly Gulch (Tributary of Greenhorn Creek) (MT41I006_220)	Limited data
Granite Creek from headwaters to mouth (Austin Creek – Greenhorn Creek – Sevenmile Creek) (MT41I006_179)	No representative data
Jennie's Fork from the Headwaters to the Mouth (MT41I006_210)	Limited data
Silver Creek from the Headwaters to the Mouth (MT41I006_150)	Borderline copper levels, limited mercury data
Lake Helena	Borderline cadmium

2.4.2 Refinement of Metals Sources and Seasonality

The presently available metals monitoring data include limited runoff sampling events and, as such, the importance of wet weather-related metals sources may be under-represented in the source allocations. The data generated from the metals impairment confirmation monitoring described above would be screened to examine general locations of metals sources. In instances where very large in-stream increases are noted, especially during wet weather monitoring events, additional source assessment monitoring and field reconnaissance may be required to positively identify and quantify sources of metals loading.

2.4.3 Addressing Modeling Uncertainties

Additional metals monitoring are needed to better refine the LSPC modeling analysis. For example, one limitation of the LSPC model is that, in the absence of better data, it assumed the same metals soil concentrations on a unit-weight basis throughout the watershed. Sampling of sediment metals concentrations by sediment source and by geographic location is recommended to improve this aspect of the model. In addition, it was difficult to calibrate the model to storm events because of a lack of available data during these periods. Monitoring of storm water runoff from representative sources should therefore be performed to better estimate the concentration of metals during wet weather events.

2.5 Temperature Monitoring Strategy

Future water temperature monitoring in the Lake Helena watershed should address the following objectives:

- Uncertainties associated with impairment determinations
- Refinement of impairment causes and seasonality

2.5.1 Addressing Temperature Impairment Uncertainties

The frequency, magnitude, and timing of temperature impairments in Prickly Pear and McClellan creeks are not well documented and additional data collection is recommended to confirm suspected problems and to fine-tune restoration approaches. In-stream temperature monitoring should be conducted at several locations from June to October for a representative time period that includes wet, dry, and normal precipitation years. This time period is when flow levels and warmer air temperatures create concerns for resident fisheries. Continuous recording thermographs set to record temperature every half hour should be deployed at established Prickly Pear Creek sampling sites in the segments of concern, as well as at additional monitoring sites to fill voids in the available data. The Montana DEQ's Standard Operating Procedures (SOP) for Temperature Data Loggers should be employed to ensure that quality data are collected (see Section 5.0 of this appendix).

2.5.2 Refinement of Temperature Impairment Causes

The various causes that contribute to temperature impairments in Prickly Pear and McClellan creeks are poorly quantified and additional data collection is recommended to determine their relative importance and to adjust restoration approaches, if warranted. At a minimum, additional temperature data need to be collected for wastewater discharges, and additional streamflow/hydrologic information is needed for Prickly Pear Creek and its tributaries. Riparian condition assessments or percent shade measurements along Prickly Pear Creek are also desirable but are a much lower priority than the other monitoring needs.

The permitted point source dischargers along lower Prickly Pear Creek should monitor the temperature of their effluent at least monthly during a representative one-year time period (Table 2-5). Ambient temperature monitoring upstream and well downstream of the point source outfall locations is also recommended.

Table 2-5. Point source discharge temperature monitoring stations for lower Prickly Pear Creek.

Segment	MPDES Permit	Description
MT41I006_040	MT0000451	Ash Grove Cement Company*
MT41I006_040	MT0000426	Air Liquide America Corporation
MT41I006_040	MT0030147	ASARCO
MT41I006_040	MT0022560	City of East Helena WWTP
MT41I006_020	MT0000949	City of Helena WWTP

*Should discharge occur.

Late-season (August and October) synoptic streamflow monitoring runs should be conducted on Prickly Pear Creek from Montana City downstream to Lake Helena in at least two years representing wet and dry weather conditions. Flow gaging sites should be adequately spaced such that inflows from tributaries and outflows from diversions are adequately captured. Streamflow gaging should be conducted according to the Montana Water Quality Monitoring Standard Operating Procedures (SOP) (see Section 5.0). This task could be readily accomplished as an add-on to the hydrologic studies that are described in Section 2.1 above.

2.6 Modeling Tool Development

Relatively simple models (GWLF and BATHTUB) were chosen to simulate nutrient and sediment loads in the Lake Helena watershed. This was primarily due to the lack of data necessary to calibrate a more complex nutrient and sediment model (see Appendix C). The GWLF and BATHTUB models provided monthly output, and were not capable of simulating daily interactions between nutrients, dissolved oxygen, and in-stream algal growth.

More complex models are available to simulate nutrient and sediment loads and could be used in the ongoing management of the Lake Helena watershed. For example, they could be used to more thoroughly evaluate the impacts of various wastewater treatment controls in Prickly Pear Creek, or to evaluate possible residential development within the watershed. Potential impacts with and without increased levels of controls can be evaluated and compared to expected costs so that water quality impacts are factored into planning decisions.

The Loading Simulation C++ model (LSPC) is a watershed model that is capable of providing hourly output, and is capable of simulating the interactions between nutrient loads, dissolved oxygen, and algae. LSPC has already been set up to model metals in the Lake Helena watershed, and could also be used to model nutrients and sediment loads. Output from LSPC could be directly compared to Montana DEQ's numeric dissolved oxygen criteria, and to potential targets for algae (phytoplankton or periphyton). Furthermore, hourly (or daily) nutrient loads and concentrations are better suited for determining compliance with water quality targets and standards.

Similarly, a more complex lake model such as the Army Corps of Engineers CE-QUAL-W2 model could be used to simulate conditions in Lake Helena and possibly Hauser Reservoir. CE-QUAL-W2 is also capable of modeling nutrient-DO-algae interactions, and provides hourly output. Furthermore, the CE-QUAL-W2 model can be linked to the LSPC watershed model.

Much of the additional data needed to calibrate the LSPC and CE-QUAL-W2 models is described in Sections 2.1, 2.2 and 2.3. Water quality samples should be collected at least at a monthly frequency, and should also target storm events, low-flows events, and baseflow events to allow for model calibration during these periods. Additional data that would allow for a more thorough calibration include:

- Detailed imperviousness study of the urban areas of the watershed.
- Representative sampling of groundwater nutrient concentration throughout the watershed.

3.0 IMPLEMENTATION MONITORING

The purpose of implementation monitoring is to document whether or not management practices were applied as designed. Objectives of an implementation monitoring program include:

- Measuring, documenting, and reporting the watershed-wide extent of BMP implementation and other restoration measures, including point source controls
- Evaluating the general effectiveness of BMPs as applied operationally in the field.
- Determining the need and direction of BMP education and outreach programs

Implementation monitoring consists of detailed visual monitoring of BMPs, with emphasis placed on determining if they were implemented or installed in accordance with approved design criteria. This type of information would create an inventory of where BMPs have been applied as well as their site-specific effectiveness. The various watershed stakeholders should take the lead in performing the implementation monitoring because it is likely to vary by the type of BMPs that are applied, by geographic location and, perhaps, by land ownership or management jurisdiction. For example, the USFS has the most expertise in assessing forestry BMPs whereas the City of Helena personnel are most familiar with urban storm water controls.

Additional discussion regarding implementation monitoring is not presented herein. It is envisioned that the watershed stakeholders responsible for implementation activities will work with EPA, DEQ, and the local watershed protection district under the umbrella of the Lake Helena Watershed Committee to develop implementation monitoring plans on a case-by-case basis.

4.0 EFFECTIVENESS MONITORING AND ADAPTIVE MANAGEMENT

Montana statutes require that MDEQ evaluate all TMDLs for their effectiveness five years after they have been completed and approved (MCA 75-5-703(9)(c)). A formal review of the Lake Helena TMDL will therefore be conducted in 2011. The review will use the water quality targets that have been identified for each pollutant in the Lake Helena restoration plan to assess overall progress toward meeting the stated water quality restoration goals. This effort will include a combination of water quality and biological monitoring and habitat assessments collectively aimed at determining the effectiveness of the various restoration measures. Although this assessment can be made based on data collected by MDEQ only in year five, a much more thorough assessment will be possible if additional data are collected during the intervening years. Due to MDEQ resource constraints, these additional data will need to be collected by watershed stakeholders. Some suggested effectiveness monitoring activities are presented below and additional measures may be selected by stakeholders within the proposed Lake Helena Watershed Committee. In addition to evaluating the overall effectiveness of the Lake Helena plan in restoring water quality, the various proposed effectiveness monitoring elements will provide a feedback mechanism that can be used to verify TMDL assumptions and to fine-tune restoration approaches through adaptive management.

4.1 Nutrients

Nutrient effectiveness monitoring in Prickly Pear Creek should consist of monthly sampling of general water quality in 2011, as well as targeted collection of attached algae and dissolved oxygen data during the critical summer months. One purpose of this monitoring is to assess the degree to which the implemented point and non-point source controls have reduced ambient nutrient concentrations compared to the available historical data. Another purpose is to determine whether in-stream nutrient reductions have lead to corresponding decreases in algal standing crops and the magnitude of dissolved oxygen sags. Nutrient effectiveness monitoring should also be conducted in Lake Helena and Hauser Reservoir in 2011 using the nutrient/limnologic parameters that were previously described in Section 2.3 above.

4.2 Sediment

Sediment water quality endpoints should be assessed on a maximum interval of five years in order to judge the degree of target acquisition. However, biannual data collection at fixed plots is more applicable, and should be conducted following the implementation of restoration activities, with subsequent data collection in every fifth year. Three years of data collection every five years will provide a basis for trend analysis, and an evaluation of the level of in-stream benefits associated with the various restoration measures. The exception to the biannual data collection strategy is suspended sediment sampling, which should occur on a more frequent basis (quarterly, if resources can support this level of intensity).

4.3 Temperature

Temperature monitoring of Prickly Pear Creek segments should be conducted seasonally for a minimum of three years following the implementation of control measures. Montana DEQ protocols should be used for all sampling events, and the data should be recorded and submitted to the MDEQ. The effectiveness monitoring strategy for temperature should include in-stream temperature and streamflow monitoring and the collection of weather data to determine representativeness of the results. Records from the nearest NOAA weather station should be used to monitor local weather for the area of interest. The three active NOAA climate stations in the Lake Helena watershed are listed in Table 4-1. If a local weather station is not found that can provide the appropriate information, then an optional weather station capable of logging parameters such as temperature, barometric pressures, wind speed, precipitation, dew point, or solar radiation may be deployed.

Table 4-1. Active NOAA climate stations in the Lake Helena Watershed.

Station Name	Coop-ID	Elevation (ft)
Austin 1 W	240375-4	4,790
Helena WSO	244055-4	3,830
Rimini 4 NE	247055-4	4,700

4.4 Metals

Effectiveness monitoring for metals should consist of sampling the metals of concern, along with hardness, pH, and instantaneous flow. Monthly sampling in 2011 is recommended at the mouth of every listed segment throughout the Lake Helena watershed. Additional sampling during runoff events (from snowmelt and summer storms) is also recommended. The data will be evaluated for the presence and spatial persistence of any numeric criteria violations.

5.0 SAMPLING AND ANALYSIS METHODS AND QUALITY ASSURANCE CONSIDERATIONS

Where applicable, MDEQ standard operating procedures should be followed for the sampling described herein to ensure consistency across statewide TMDL monitoring programs. MDEQ methods are described in the following document:

- Montana Water Quality Monitoring Standard Operating Procedures (SOP) (available at: http://deq.mt.gov/wqinfo/monitoring/SOP/sop.asp, specifically sections:
    - 10.0 – Sample Collection
    - 11.0 – Methods for Collecting, Analyzing, and Reporting Water Quality and Sediment Chemical Data
    - 12.0 – Methods of Assessing the Biological Integrity of Surface and Groundwater
    - 13.0 – Methods for Assessing the General Health and Physical Integrity of Surface Waters.

Quality assurance and quality control (QA/QC) procedures for all monitoring, assessment, and reporting activities described in this appendix should be addressed in a monitoring quality assurance project plan (QAPP) developed specifically for the Lake Helena restoration project. The QAPP should be developed following MDEQ guidance available at: http://deq.mt.gov/wqinfo/QAProgram/index.asp.

Appendix I

Phased Wasteload Allocation Strategy

Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report

August 31, 2006

Prepared for the Montana Department of Environmental Quality

Prepared by the U.S. Environmental Protection Agency,
Montana Operations Office
With Technical Support from Tetra Tech, Inc.
and PBS&J, Inc.

Project Manager: Ron Steg

Contents

1.0 Introduction 1
2.0 Proposed Approach 3
3.0 Coordination and Timing 5
4.0 Adaptive Management 7
5.0 References 9

1.0 INTRODUCTION

There are nine centralized wastewater treatment systems in the Lake Helena Watershed:

- Eastgate Subdivision
- Treasure State Acres Subdivision
- Tenmile and Pleasant Valley Subdivisions
- Leisure Village Mobile Home Park
- Mountain View Academy
- Fort Harrison (closed)
- Evergreen Nursing Facility
- City of Helena WWTP
- City of East Helena WWTP
- Golden Estates Subdivision

These facilities are described in Appendix C and E. Total nitrogen and total phosphorus loads were estimated from each of these facilities and the loads were put into context with the loads from all other potential sources in the watershed. The City of Helena and East Helena comprise approximately 17 and 4 percent of the total nitrogen load, and 38 and 3 percent of the total phosphorus load, respectively, in the Prickly Pear Creek Watershed. Loads from the remaining facilities are negligible at the Prickly Pear Creek Watershed scale (i.e., each comprising less than 1 percent of the total load).

It has been estimated that it will be necessary to reduce overall TN and TP loading in the Prickly Pear Creek Watershed by 80 and 87 percent, respectively, to attain the interim nutrient targets presented in Section 3.2.3 of Volume II (i.e., TN = 0.33 mg/l, TP = 0.04 mg/l). To attain nutrient load reductions of this magnitude, it will be necessary to seek the maximum attainable nutrient load reductions from all significant point and nonpoint sources.

This document presents a phased plan to reduce nutrient loading from the City of Helena and City of East Helena wastewater treatment plants. A phased approach is proposed in recognition of the fact that both the Cities of Helena and East Helena have recently committed significant amounts of money to upgrade their facilities and, further upgrades to reduce nutrient loading may pose both financial and technical challenges. A phased approach is also necessary given uncertainty over the ability to attain the nutrient targets in Prickly Pear Creek (see Volume II, Section 3.2.3.1) and because potential nutrient limits to protect Lake Helena and Hauser Reservoir have not yet been identified. This phased plan also incorporates considerable flexibility through an adaptive management strategy presented in Section 4.0.

2.0 PROPOSED APPROACH

The proposed approach includes three phases, where nutrient discharge concentrations and loads will be reduced in steps. Phase I is voluntary. The goal of Phase I ("No Increases") is to limit TN and TP concentrations and loads to the existing levels (as calculated based on past performance of the two facilities) while further studies are conducted to:

- Better understand the impact of the wastewater discharges on Prickly Pear Creek,
- Evaluate current facility operations to optimize the level of treatment that can be attained with the current infrastructure, and conduct an alternatives analysis/feasibility study to determine the cost and technological requirements for meeting the nutrient targets
- Better understand water quality conditions and appropriate nutrient limits for Lake Helena and Hauser Reservoir

The goal of Phase II ("Optimization") is to begin to reduce nutrient concentrations and loads by optimizing the infrastructure that currently exists. The goal of Phase III ("Water Quality-Based Limits") is to implement the necessary actions to reach the level of treatment to meet the TP and TN targets for Prickly Pear Creek.

Concentration and load limits for the three phases and both facilities are presented in Table 2-1. It should be noted that the limits presented in Table 2-1 will likely be modified in the future in accordance with the adaptive management strategy outlined in Volume II, Section 3.2.3.1 and the adaptive management strategy discussed below.

Table 2-1. Tentative Concentration and Load Limits.

Phase	Target	City of Helena		City of East Helena	
		Limits	Percent Reduction from Current	Limits	Percent Reduction from Current
Phase I	TP Concentration (mg/l)	5.02	0%	3.6	0%
	TP Load (tons/yr)	22.2	0%	0.99	0%
	TN Concentration (mg/l)	7.7	0%	23.2	0%
	TN Load (tons/yr)	34.1	0%	6.41	0%
Phase II	TP Concentration (mg/l)	1.0	80%	1.0	72%
	TP Load (tons/yr)	8.57	61%	0.59	40%
	TN Concentration (mg/l)	4.0	48%	4.0	83%
	TN Load (tons/yr)	34.28	0%	2.37	63%
Phase III	TP Concentration (mg/l)	0.04	99%	0.04	99%
	TP Load (tons/yr)	0.34	98%	0.02	98%
	TN Concentration (mg/l)	0.33	96%	0.33	99%
	TN Load (tons/yr)	2.83	92%	0.19	97%

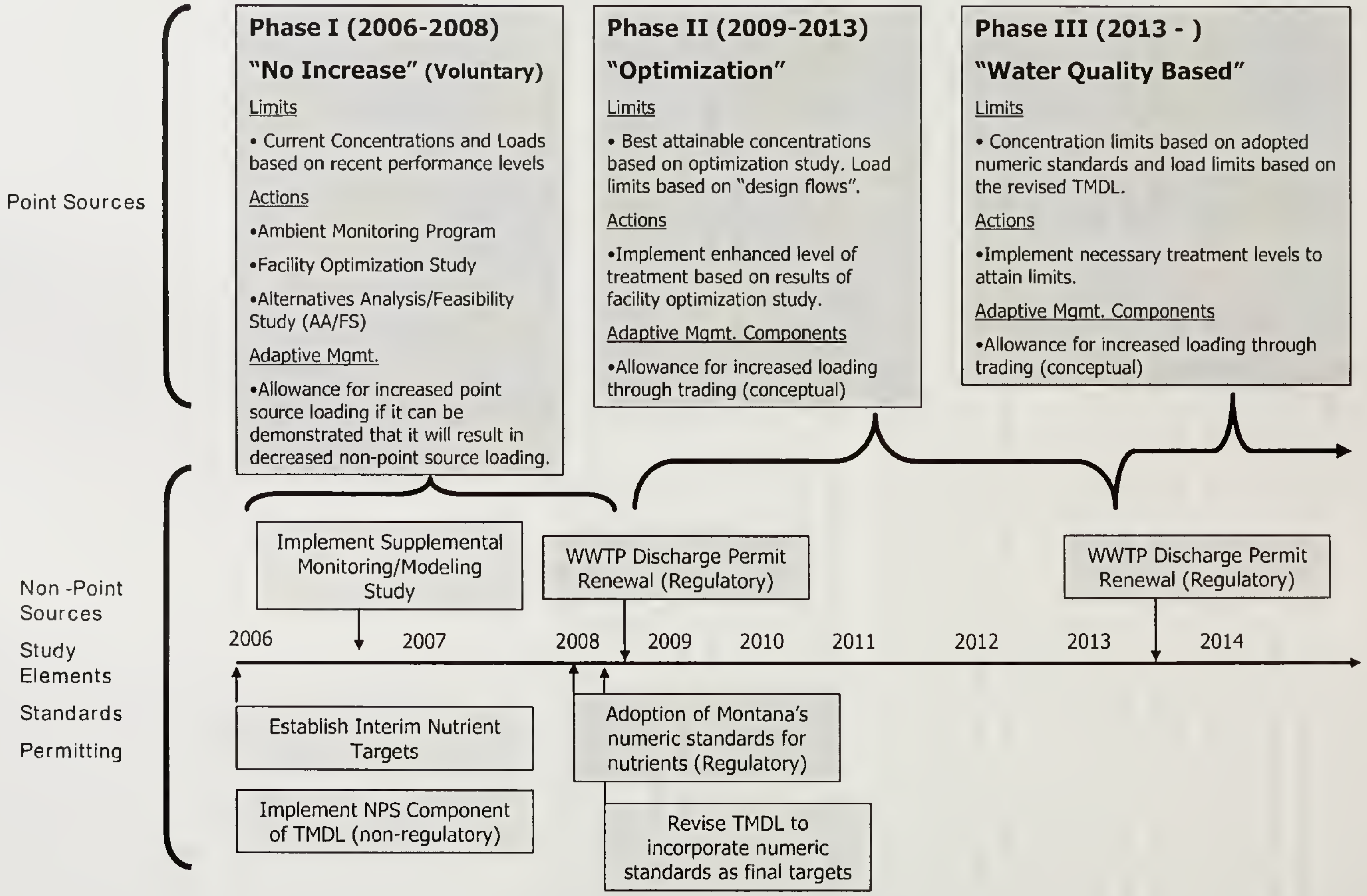
The voluntary Phase I concentration limits are based on current performance. For the City of Helena, the concentrations are based on monthly averages from June 2001 through January 2005 (post upgrade). For the City of East Helena, the concentrations are based on monthly averages from March 2003 to May 2005 (post upgrade). TP and TN loads are based on concentrations multiplied by a conversion factor (1.3825) and the average observed effluent flow (3.20 million gallons per day (MGD) for City of Helena and 0.20 MGD for the City of East Helena). The Phase II concentration limits are based on the best attainable level of treatment in the literature (EPA, 1997). The Phase II load limits assume design flows of 6.2 and 0.43 MGD for Helena and East Helena, respectively. The Phase III concentration limits are the TN and TP targets presented in Section 3.2.3 of Volume II. Concentration limits for all three phases are 30-day averages.

3.0 COORDINATION AND TIMING

Point sources are regulated through the National Pollutant Discharge Elimination System (NPDES) Program. According to the Montana Water Quality Act (MCA 75-5-703 (6) (b)), after development of a TMDL and upon approval of the TMDL, MTDEQ is required to incorporate waste load allocations developed for point sources during the TMDL process into appropriate wastewater discharge permits. As shown in Figure 3-1, the proposed approach has been coordinated, in time, with point source discharge permit renewals and the rule making process for adoption of numeric standards for nutrients.

In recognition of the fact that nutrient loads need to be reduced as soon as possible, implementation of the largely non-regulatory non-point source controls is proposed as the first step in the proposed approach. Although it is proposed that non-point source controls be implemented immediately, it is acknowledged that implementing non-point source controls may be an ongoing process for many years. During the initial two to three years of the implementation phase of this approach, point source dischargers are also asked to voluntarily conduct monitoring, and optimization and feasibility studies to develop a better understanding of the fate of their discharges in the receiving water bodies and to determine the technological and financial practicality of solutions to reduce point source nutrient loading (see Figure 3-1). The point source dischargers are also asked to voluntarily maintain existing TN and TP effluent concentrations and loads (i.e., no increases) during this phase.

As a parallel effort, EPA and DEQ are committed to conducting the "supplemental study elements" presented in Volume II, Section 3.2.3.2. Additionally, DEQ will proceed with the rule making process for the adoption of numeric nutrient standards. Ultimately, these two efforts will result in the selection of "final" nutrient threshold values for the waters in the Lake Helena Watershed. Upon adoption by the Montana Board of Environmental Review, they will be officially incorporated into rule. Once this is complete, the nutrient targets (see Volume II, Section 3.2.3) and associated TMDLs in Appendix A will be revised and wastewater discharge permits will be officially renewed using the revised targets (i.e., official standards at that point in time) to develop water quality based discharge limits. Point source dischargers will be provided time to make the necessary infrastructure upgrades. During this time period, point source dischargers will be expected to meet limits based on the optimization study conducted previously.



Phase I (2006-2008)

"No Increase" (Voluntary)

Limits

- Current Concentrations and Loads based on recent performance levels

Actions

- Ambient Monitoring Program
- Facility Optimization Study
- Alternatives Analysis/Feasibility Study (AA/FS)

Adaptive Mgmt.

- Allowance for increased point source loading if it can be demonstrated that it will result in decreased non-point source loading.

Phase II (2009-2013)

"Optimization"

Limits

- Best attainable concentrations based on optimization study. Load limits based on "design flows".

Actions

- Implement enhanced level of treatment based on results of facility optimization study.

Adaptive Mgmt. Components

- Allowance for increased loading through trading (conceptual)

Phase III (2013 -)

"Water Quality Based"

Limits

- Concentration limits based on adopted numeric standards and load limits based on the revised TMDL.

Actions

- Implement necessary treatment levels to attain limits.

Adaptive Mgmt. Components

- Allowance for increased loading through trading (conceptual)

Point Sources
Non -Point Sources
Study Elements
Standards
Permitting
Implement Supplemental Monitoring/Modeling Study
WWTP Discharge Permit Renewal (Regulatory)
WWTP Discharge Permit Renewal (Regulatory)
2006
2007
2008
2009
2010
2011
2012
2013
2014
Establish Interim Nutrient Targets
Implement NPS Component of TMDL (non-regulatory)
Adoption of Montana's numeric standards for nutrients (Regulatory)
Revise TMDL to incorporate numeric standards as final targets

Figure 3-1. Coordinated Implementation Schedule for Point and Non-Point Source Nutrient Reduction Strategy (all dates are tentative).

4.0 ADAPTIVE MANAGEMENT

There are a number of adaptive management elements incorporated into this proposed phased wasteload allocation plan to provide a mechanism to adjust the limits and timeline based on new or improved information. For example, the Phase II concentration limits are based on treatment levels achievable with various combinations of unit operations and processes as documented in the literature (e.g., EPA, 1997). Final limits will be determined using the results of the facility optimization evaluations conducted in Phase I. The adaptive management strategy presented in Volume II, Section 3.2.3.1, addressing the nutrient targets, provides a mechanism to facilitate modification of the Phase III limits, if deemed appropriate or necessary in the future. Also, the concept of effluent trading is proposed as a means to modify the load limits in the waste load allocations, assuming that it results in an overall watershed scale nutrient load reduction. The details would have to be worked out through the MPDES permit process.

5.0 REFERENCES

EPA. 1997. Technical Guidance Manual for Developing Total Maximum Daily Loads: Book 2: Streams and Rivers: Part 1: Biochemical Oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication. EPA 823-B-97-002. Office of Water (4305). March 1997.

Appendix J

Wasteload Allocations for Regulated Stormwater Discharges

Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report

August 31, 2006

Prepared for the Montana Department of Environmental Quality

Prepared by the U.S. Environmental Protection Agency,
Montana Operations Office
With Technical Support from Tetra Tech, Inc.
and PBS&J, Inc.

Project Manager: Ron Steg

1.0 INTRODUCTION

In accordance with internal EPA guidance provided in a November 22, 2002 memorandum (Wayland, 2002), NPDES-regulated storm water discharges must be addressed by the Wasteload Allocation (WLA) component of a TMDL. Table 1 provides a summary of the storm water discharges regulated within the Lake Helena Watershed. Locations are shown on Figure 1. A description of all of the permitted storm water discharges and associated WLAs are presented in the remainder of this appendix.

Table 1. Regulated Storm Water Discharges within the Lake Helena Watershed.

Name	Permit Number	Permit Type	Permit Expiration	Subwatershed(s)	Receiving Water Body(ies)
City of Helena	MTR0400000	General Permit - Small Municipal Separate Storm Sewer Systems	12/31/09	Tenmile Creek and Prickly Pear Creek	Tenmile Creek and Prickly Pear Creek
Montana Department of Transportation	MTR0400000	General Permit - Small Municipal Separate Storm Sewer Systems	12/31/09	Tenmile Creek and Prickly Pear Creek	Tenmile Creek and Prickly Pear Creek
Helena Regional Airport	MTR000271	General Permit - Industrial	9/30/06	Prickly Pear Creek	Prickly Pear Creek, Helena Irrigation Canal, the City of Helena sewer system, and groundwater
National Guard	MTR000428	General Permit - Industrial	9/30/06		
UPS	MTR000334	General Permit - Industrial	9/30/06		
Montana Rail Link	MTR000361	General Permit - Industrial	9/30/06	Prickly Pear Creek	Helena Valley Irrigation Ditch
Pacific Steel and Recycling	MTR000430	General Permit - Industrial	9/30/06	Prickly Pear Creek	City of Helena Storm Sewer/ Tenmile Creek
ASARCO	MTR000072	General Permit - Industrial	9/30/06	Prickly Pear Creek	Prickly Pear Creek
Ash Grove Cement Company	MTR300113	General Permit - Mining and Oil and Gas Activities	10/2007	Prickly Pear Creek	Prickly Pear Creek
Air Liquide	MTR0000006	General Permit - Industrial	9/30/06	Prickly Pear Creek	Prickly Pear Creek
Lewis and Clark County Landfill	MTR000363	General Permit - Industrial	9/30/06	Overland Flow	Helena Valley Irrigation Ditch
Miscellaneous Construction Sites		General Permit - Construction	12/31/06	Misc.	Misc.

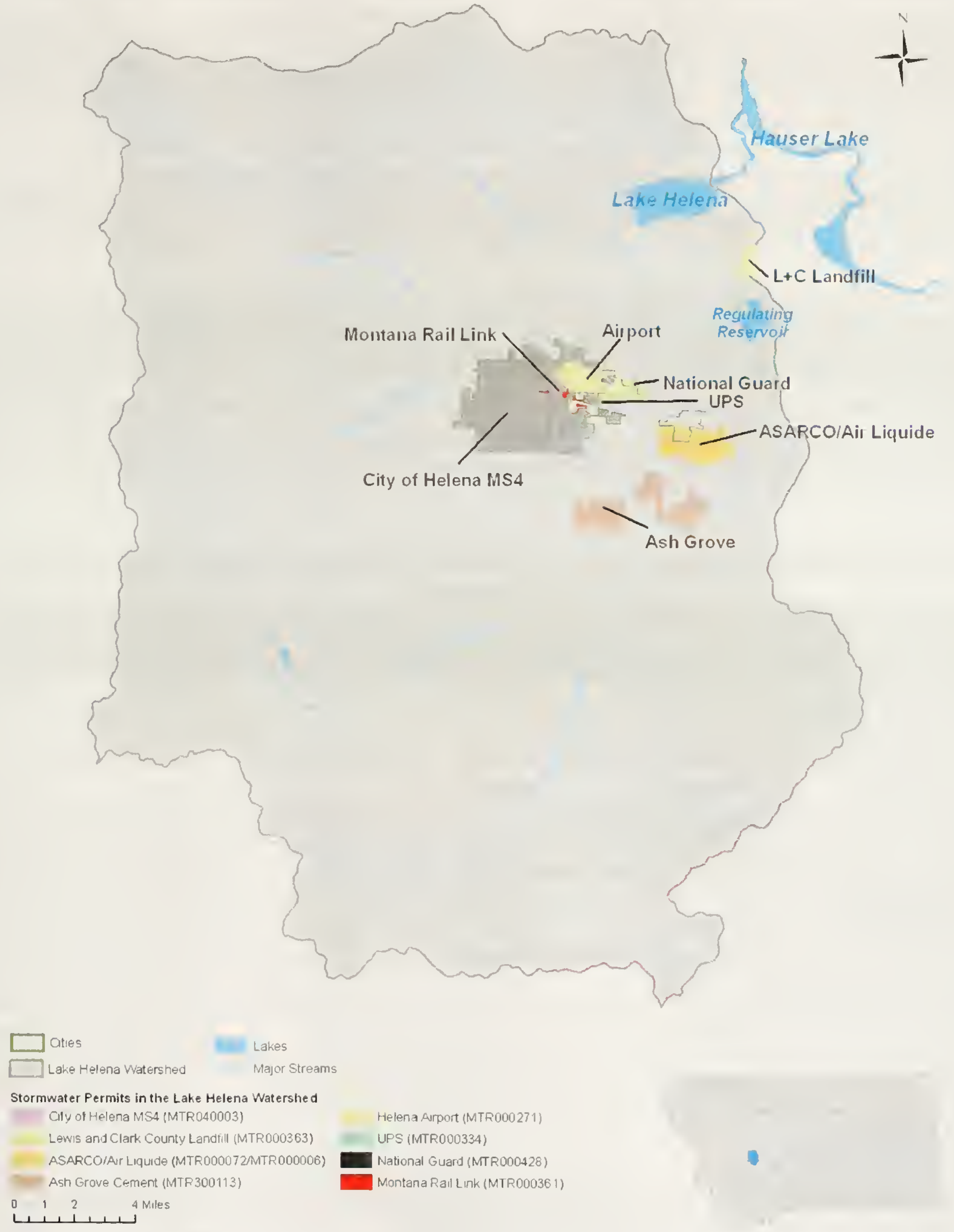

N
Hauser Lake
Lake Helena
L+C Landfill
Regulating Reservoir
Montana Rail Link
Airport
National Guard
UPS
ASARCO/Air Liquide
City of Helena MS4
Ash Grove
Cities
Lakes
Lake Helena Watershed
Major Streams
Stormwater Permits in the Lake Helena Watershed
City of Helena MS4 (MTR040003)
Helena Airport (MTR000271)
Lewis and Clark County Landfill (MTR000363)
UPS (MTR000334)
ASARCO/Air Liquide (MTR000072/MTR000006)
National Guard (MTR000428)
Ash Grove Cement (MTR300113)
Montana Rail Link (MTR000361)
0 1 2 4 Miles

Figure 1. Facilities in the Lake Helena watershed with stormwater permits.

From a practical standpoint, "stormwater" is typically considered storm-event generated runoff from impervious surfaces. The GWLF model (Appendix C) represented stormwater primarily through the evaluation of two source categories (i.e., "urban" and "paved roads"). The relative importance of total nitrogen (TN), total phosphorus (TP), and sediment loading from stormwater is shown in Table 2. In general, stormwater TN, TP, and sediment loading represents less than 16, 13, and 3 percent, respectively, of the total loads. The regulated stormwater facilities only comprise 2.41, 4.27, and 3.40 percent, respectively, of the Tenmile, Prickly Pear, and Lake Helena Watersheds (Table 3). Assuming a linear relationship between land area and pollutant loading, it is estimated that the permitted stormwater facilities comprise only a small fraction of the total TN, TP, and sediment loading to the Tenmile, Prickly Pear, and Lake Helena Watersheds – less than half a percent (Table 4).

Table 2. Relative Importance of Stormwater Pollutant Loading (% of Total Load).

Source Category	Tenmile Watershed			Prickly Pear Watershed			Lake Helena Watershed		
	TN	TP	TSS	TN	TP	TSS	TN	TP	TSS
Paved Roads	3.2%	2.5%	0.0%	2.5%	1.4%	0.0%	1.6%	1.2%	0.0%
Urban	12.7%	10.3%	3.0%	7.3%	3.9%	2.2%	6.2%	4.3%	NA
"Stormwater" Total	15.9%	12.8%	3.0%	9.8%	5.3%	2.2%	7.8%	5.5%	NA

Table 3. Approximate Land Area Covered by Stormwater Permitted Facilities in the Lake Helena Watershed.

Name	Permit Number	Total Area (acres)	% of Tenmile Watershed	% of Prickly Pear Watershed	% of Lake Helena Watershed
City of Helena[1]	MTR0400000	7700.0	2.41%	2.50%	1.94%
Montana Department of Transportation	MTR0400000				
Helena Regional Airport	MTR000271	1430.0	NA	0.46%	0.36%
National Guard	MTR000428	3.9	NA	0.00%	0.00%
UPS	MTR000334	22.6	NA	0.01%	0.01%
Montana Rail Link[2]	MTR000361	70.2	NA	0.02%	0.02%
Pacific Steel and Recycling[3]	MTR000430	0.64	NA	0.00%	0.00%
ASARCO/Air Liquide	MTR000072/ MTR0000006	1,584.0	NA	0.51%	0.40%
Ash Grove Cement Company	MTR300113	2387.5	NA	0.78%	0.60%
Lewis and Clark County Landfill	MTR000363	326.4	NA	N/A	0.08%
Miscellaneous Construction Sites					
Total		13,454.4[4]	2.41%	4.26%	3.40%

[1] City of Helena is 8953 acres, which partially contains the Helena Airport. The overlapping area between the City and airport was removed from the analysis so that the new City of Helena area is 7700 acres.

[2] The Montana Rail Link Facility is mostly contained within the City of Helena and corresponding stormwater permit.

[3] Pacific Steel is completely within the City of Helena and corresponding stormwater permit.

[4] Pacific Steel and Recycling and Montana Rail Link were not included in the total area so that land was not double counted.

Table 4. Relative Importance of Stormwater Pollutant Loading from Regulated Stormwater Discharges (Percent of Total Load).

Source Category	Tenmile Watershed			Prickly Pear Watershed			Lake Helena Watershed		
	TN	TP	TSS	TN	TP	TSS	TN	TP	TSS
Stormwater Total	0.38%	0.31%	0.07%	0.42%	0.26%	0.09%	0.26%	0.19%	NA

Given the fact that regulated stormwater contributes only a small fraction of the total pollutant load, and the fact that each of the facilities listed in Table 1 are currently authorized to discharge by MTDEQ, no new requirements are proposed for regulated stormwater at this time.

However, it is recommended that monitoring and/or model-based evaluations be conducted to estimate pollutant removal efficiencies associated with all structural and non-structural BMPs at each permitted facility. Upon permit renewal, facilities should establish numeric pollutant load targets that represent the "maximum extent practicable" level of treatment. In the interim, based on literature pollutant removal efficiencies, the "maximum extent practicable" level of treatment is assumed to be 30, 50, and 80 percent removal for TN, TP, and sediment.

Appendix K

On-Site Domestic Wastewater Treatment in the Lake Helena Watershed

Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area:

Volume II – Final Report

August 31, 2006

Prepared for the Montana Department of Environmental Quality

Prepared by the U.S. Environmental Protection Agency,
Montana Operations Office
With Technical Support from Tetra Tech, Inc.
and PBS&J, Inc.

Project Manager: Ron Steg

Contents

1.0 Introduction 1
2.0 State and Local Regulations 2
2.1 State Regulations 4
2.1.1 General Regulations 4
2.1.2 Design, Preparation, and Installation Regulations 5
2.1.3 Antidegradation Regulations 6
2.1.4 Permitting 8
2.2 County Regulations 8
2.2.1 Lewis and Clark County Regulations 8
2.2.2 Jefferson County Regulations 9
3.0 Conventional Wastewater Treatment Systems 10
3.1 Conventional Onsite Systems 10
3.2 Clustered and Centralized Systems 12
4.0 Alternative Wastewater Treatment Systems 14
5.0 Treatment System Cost 15
6.0 Comparison of Systems 16
7.0 References 17

1.0 Introduction

On-site domestic wastewater from privately owned septic systems is one of the largest sources of nitrogen and phosphorus to Lake Helena and many of its tributary streams. This document provides a summary of the state and local regulations regarding septic systems, a review of the literature regarding treatment efficiency of conventional and alternative septic systems, and a comparison of cost and treatment efficiency for a variety of septic system designs.

2.0 State and Local Regulations

In Montana, the state, cities, and counties have the authority to regulate subsurface wastewater treatment systems (SWTS). The regulating authorities in the Lake Helena watershed are the State of Montana, Lewis and Clark County, and Jefferson County. The role of the three entities differs based on the type, location, size, and purpose of the wastewater treatment system.

Small, privately owned onsite treatment systems must meet the design requirements specified in Montana Department of Environmental Quality (MDEQ) Circular 4 (Montana Standards For Subsurface Wastewater Treatment Systems), and the rules and prohibitions described in the Administrative Rules of Montana (ARM) 17.36.9 (On-Site Subsurface Wastewater Treatment Systems). However, the counties (i.e., Lewis and Clark County and Jefferson County) issue permits and inspect all small, privately owned systems. Counties may also require system upgrades and issue fines for existing out of compliance systems.

Lewis and Clark County also has more stringent regulations than contained in ARM 17.36.9. Regulations are based on the type of soils and depth to groundwater, and in some cases require pressure dosed or level 2 treatment (Lewis and Clark County, 2006). Jefferson County regulations are the same as the state regulations, and are no more stringent. By meeting the regulations specified in Circular 4 and ARM 17.36.9, most small onsite systems, by default, meet the criteria for creating a "non-significant" change in water quality, and a nondegradation analysis is not required.

Both the counties and the state regulate and permit larger wastewater treatment systems (e.g., three or more houses, larger subdivisions, and city systems). Larger systems must meet the design requirements specified in MDEQ Circular 4 and the rules and prohibitions described in ARM 17.36.3 (Subdivision Requirements). MDEQ issues ground water discharge permits (under the Montana Ground Water Pollution Control System Rules, ARM 17.30.10) to certain types of larger onsite systems. Typically, systems with a design flow over 5,000 gpd are required to obtain a discharge permit if they are new or modified after May 1, 1998. Montana DEQ also inspects the systems that are permitted by the state (Personal Communications, Eric Regensburger, June 12, 2006). The two counties then issue the permits to construct and maintain the larger treatment systems. The counties are also responsible for conducting a nondegradation analysis, per the requirements in ARM 17.30.7 and the guidelines in the MDEQ document, "How to Perform a Nondegradation Analysis for Subsurface Wastewater Treatment Facilities," (MDEQ, 2005).

The full regulations, circulars, and guidance pertaining to all SWTS can be found in the documents summarized in Table 1. Regulations for Montana, Lewis and Clark County, and Jefferson County are further discussed in the following sections (Sections 2.1, 2.2.1, and 2.2.2, respectively).

Table 1. State and County regulations and guidance pertaining to subsurface wastewater treatment systems

Document	Title	Online Location	Purpose
ARM 17.36.9	On-Site Subsurface Wastewater Treatment Systems	http://www.deq.state.mt.us/ dir/legal/Chapters/Ch36-toc.asp	Montana rules and regulations for small, privately owned SWTS. Specifies setback requirements, minimum depth to groundwater requirements, and septic size requirements.
ARM 17.36.3	Subdivision Requirements	http://www.deq.state.mt.us/ dir/legal/Chapters/Ch36-toc.asp	Montana rules and regulations for larger SWTS. Specifies setback requirements, minimum depth to groundwater requirements, and allowable systems.
ARM 17.30.5	Mixing Zones in Surface and Ground Water	http://www.deq.state.mt.us/ dir/legal/Chapters/Ch30-toc.asp	Montana rules and regulations for groundwater mixing zones
ARM 17.30.7	Nondegradation of Water Quality	http://www.deq.state.mt.us/ dir/legal/Chapters/Ch30-toc.asp	Montana rules and regulations for determining if a system needs to have a nondegradation analysis performed.
ARM 17.30.10	Montana Ground Water Pollution Control System	http://www.deq.state.mt.us/ dir/legal/Chapters/Ch30-toc.asp	
Montana DEQ Circular 4	Montana Standards For Subsurface Wastewater Treatment Systems	http://www.deq.state.mt.us/ wqinfo/Circulars.asp	Provides specifications for Montana DEQ approved systems.
Montana Nondegradation Guidelines	How to Perform a Nondegradation Analysis for Subsurface Wastewater Treatment Facilities	http://www.deq.state.mt.us/ wqinfo/Nondeg/HowToNonDeReg.asp	Provides guidance for conducting a nondegradation analysis. A companion document to ARM 17.30.7.
Lewis and Clark County Regulations	On-site Wastewater Treatment Regulations	http://www.co.lewis-clark.mt.us/ health/index.php	Specifies the Lewis and Clark County SWTS regulations and summarizes the permitting process.
Jefferson County Regulations		Not Available	Specifies the Jefferson County SWTS regulations and summarizes the permitting process.

2.1 State Regulations

The State of Montana has general, antidegradation, and design regulations for onsite wastewater treatment systems. The following sections summarize these regulations.

2.1.1 General Regulations

Onsite wastewater treatment system regulations for the state of Montana are contained in the Administrative Rules of Montana (ARM) 17.36.9 (On-Site Subsurface Wastewater Treatment Systems) and ARM 17.36.3 (Subdivision Requirements). The general scope of these rules is to, "protect the public health, safety, and welfare by setting forth minimum standards for the construction, alteration, repair, extension, and use of wastewater treatment systems within the state," (ARM 17.36.911). In general, the state regulations contained in ARM 17.36.3 and 17.36.9 prohibit on-site subsurface wastewater treatment systems from (1) contaminating state waters, and (2) causing a public health hazard. The following rules also apply to all onsite treatment systems in the State of Montana:

- All wastewater treatment systems must be designed and constructed in accordance with the applicable requirements in ARM 17.36.913 and in department Circular DEQ-4, 2004 edition (i.e., Montana Standards For Subsurface Wastewater Treatment Systems) (ARM 17.36.914(1)).
- Wastewater treatment systems must be located to maximize the vertical separation distance from the bottom of the absorption trench to the seasonally high ground water level, bedrock, or other limiting layer, but under no circumstances may this vertical separation be less than **four feet** of natural soil (ARM 17.36.914(3)).
- A replacement area or replacement plan must be provided for each new or expanded wastewater treatment system. (ARM 17.36.914(4)).
- A site evaluation must be performed for each wastewater treatment system. (ARM 17.36.914(5)).
- If a department-approved public collection and treatment system is readily available within a distance of 200 feet of the property line for connection to a new source of wastewater, or as a replacement for a failed system, and the owner or managing entity of the public collection and treatment system approves the connection, wastewater must be discharged to the public system (see ARM 17.36.914(6) (a) and (b) for additional details).

Regardless of the type, all treatment systems must meet minimum setback distances as defined in ARM 17.36.918 (see Table 2). Setbacks range from 10 to 100 feet, depending on the structure and the type of treatment system.

Table 2. Minimum setback distances for onsite wastewater treatment systems.

Structure	Single User Systems		Multiple User Systems	
	Sealed or Other Components[1,2] (ft)	Absorption Systems[3] (ft)	Sealed or Other Components[1,2] (ft)	Drainfield/Sand Mounds (ft)
Public or multi-user wells/springs	100	100	100	100
Other wells	50	100	50	100
Suction lines	50	100	50	100
Cisterns	25	50	25	50
Roadcuts, escarpments	10[4]	25	10[4]	25
Slopes > 25%[5]	10[4]	25	10[4]	25
Property boundaries	10	10	10	10
Subsurface drains	10	10	10	10
Water lines	10	10	10	10
Drainfields/ sand mounds[3]	10	-	10	-
Foundation walls	10	10	10	10
Surface water, Springs	50	100	50	100
Floodplains	--[1] 100[2]	100	--[1] 100[2]	100

[1] Sealed components include sewer lines, sewer mains, septic tanks, grease traps, dosing tanks, pumping chambers, holding tanks and sealed pit privies. Holding tanks and sealed pit privies must be located at least 10 feet outside the floodplain or any openings must be at least two feet above the floodplain elevation.

[2] Other components include intermittent and recirculating sand filters, package plants, and evapotranspiration systems.

[3] Absorption systems include absorption trenches, absorption beds, sand mounds, and other drainfield type systems that are not lined or sealed. This term also includes seepage pits and unsealed pit privies.

[4] Sewer lines and sewer mains may be located in roadways and on steep slopes if the lines and mains are safeguarded against damage.

[5] Down-gradient of the sealed component, other component, or drainfield/sand mound.

2.1.2 Design, Preparation, and Installation Regulations

Besides the regulations contained in the Administrative Rules of Montana, Montana DEQ Circular 4 provides regulations for the design, preparation, and installation of all on-site wastewater treatment systems (MDEQ, 2004). All treatment systems in the State of Montana must meet the minimum requirement set forth in Montana DEQ Circular 4. Regulations are provided for site evaluations, site modifications, wastewater flow, and design and placement of the wastewater treatment systems. The process for conducting site evaluations and selecting a treatment system is regulated by the counties (i.e., Lewis and Clark or Jefferson Counties). Additional regulations for the selection, design, and placement of multiple user systems are described in ARM 17.36.320 through ARM 17.36.327.

2.1.3 Antidegradation Regulations

Antidegradation regulations, as described in ARM 17.30.7, apply to subsurface wastewater treatment systems (SWTS). A SWTS is considered to create significant or non-significant changes to water quality based on the rules described in Figure 1. In addition to the regulations specified in Figure 1, a nonsignificant SWTS must also meet one of the 5 categories described in Table 3. If a system is deemed "nonsignificant", no additional analyses are required. If a system potentially creates a "significant" change to water quality, then a nondegradation analysis must be performed. The analysis must follow the guidelines in ARM 17.30.7 and the Montana DEQ document, "How to Perform a Nondegradation Analysis for Subsurface Wastewater Treatment Facilities," (MDEQ, 2006). Per these regulations, a nitrate sensitivity analysis and a phosphorus breakthrough analysis must be performed to determine if nondegradation thresholds are met.

Table 3. Categories for determining the significance of a SWTS.

Category	Description
1	• The lot size is two acres or larger; • The percolation rate is 16 minutes per inch or slower, if a percolation test has been conducted for the drainfield; • The natural soil beneath the absorption trench contains at least six feet of very fine sand, sandy clay loam or finer soil; and • The depth to bedrock and seasonally high ground water is eight feet or greater.
2	• The drainfield is pressure-dosed; • The lot size is two acres or larger; • The percolation rate is six minutes per inch or slower, if a percolation test has been conducted for the drainfield; • The natural soil beneath the absorption trench contains at least six feet of medium sand, sandy loam or finer soil; and • The depth to bedrock and seasonally high ground water is 12 feet or greater;
3	• The drainfield is pressure-dosed; • The lot size is one acre or larger; • The subdivision consists of five lots or fewer; • There is no existing or approved SWTS within 500 feet of the subdivision boundaries; • The percolation rate is six minutes per inch or slower, if a percolation test has been conducted for the drainfield; • The natural soil beneath the absorption trench contains at least six feet of medium sand, sandy loam or finer soil; and • The depth to bedrock and ground water is 100 feet or greater.
4	• The total number of subdivision lots that were reviewed pursuant to 76-4-101 et seq., MCA, and were created in a county during the previous 10 state fiscal years is fewer than 150; and • The lot is not within one mile of the city limits of an incorporated city or town with a population greater than 500 as determined by the most recent census; or
5	• The SWTS is a level II system; • The lot size is two acres or larger; 17-2798 12/31/03 • The bottom of the drainfield absorption trenches is not more than 18 inches below ground surface; and • The depth to limiting layer (based on test pit data) is greater than six feet below ground surface.

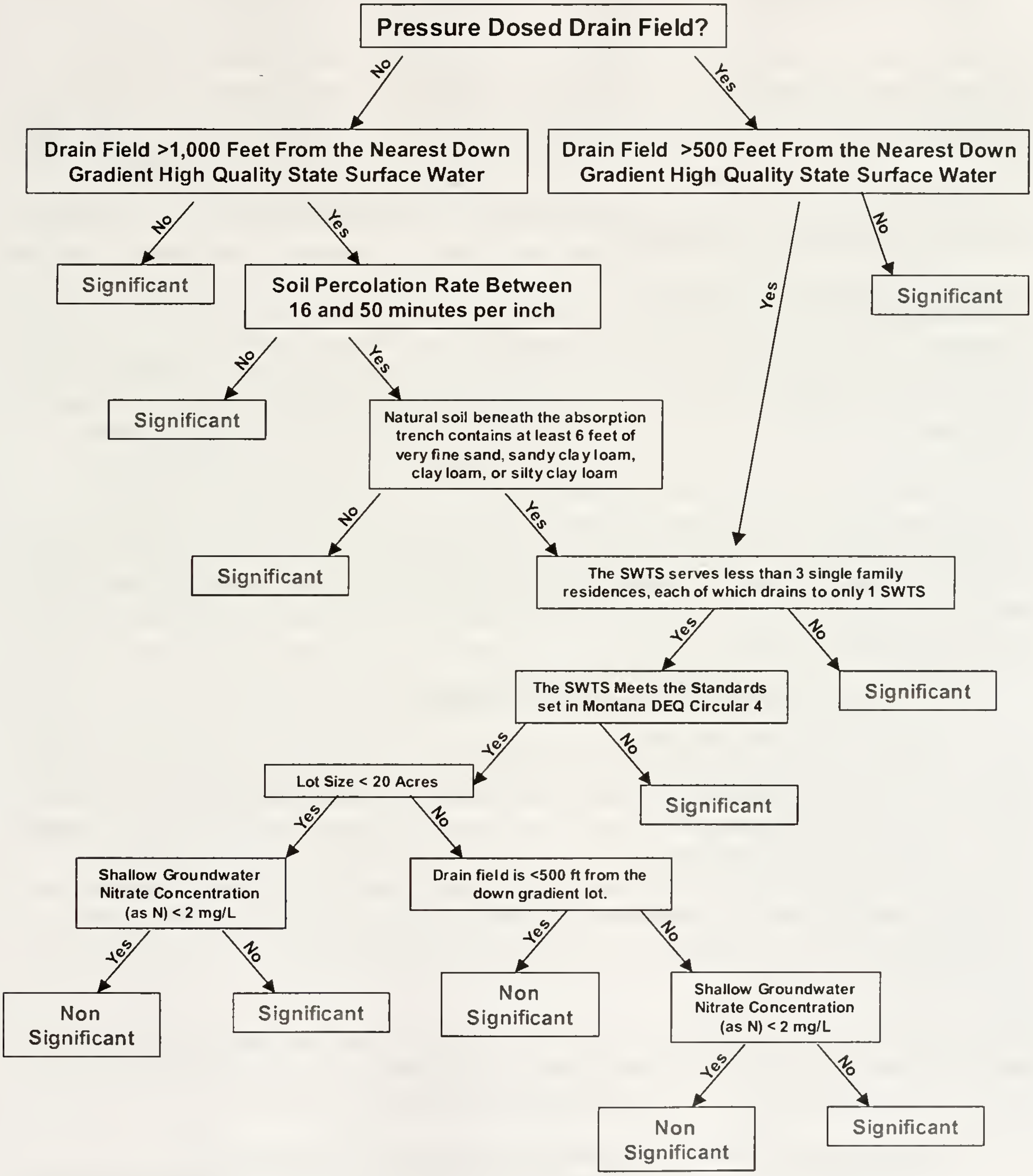

Pressure Dosed Drain Field?
No
Yes
Drain Field >1,000 Feet From the Nearest Down Gradient High Quality State Surface Water
Drain Field >500 Feet From the Nearest Down Gradient High Quality State Surface Water
No
Yes
Significant
Soil Percolation Rate Between 16 and 50 minutes per inch
Yes
No
Significant
No
Yes
Significant
Natural soil beneath the absorption trench contains at least 6 feet of very fine sand, sandy clay loam, clay loam, or silty clay loam
No
Yes
Significant
The SWTS serves less than 3 single family residences, each of which drains to only 1 SWTS
Yes
No
The SWTS Meets the Standards set in Montana DEQ Circular 4
Significant
Yes
No
Lot Size < 20 Acres
Significant
Yes
No
Shallow Groundwater Nitrate Concentration (as N) < 2 mg/L
Drain field is <500 ft from the down gradient lot.
Yes
No
Yes
No
Non Significant
Significant
Non Significant
Shallow Groundwater Nitrate Concentration (as N) < 2 mg/L
Yes
No
Non Significant
Significant

Figure 1. Method for determining the nondegradation significance of subsurface wastewater treatment systems in Montana.

2.1.4 Permitting

Montana DEQ issues ground water discharge permits (under the Montana Ground Water Pollution Control System Rules, ARM 17.30 subchapter 10) to certain types of onsite septic systems. Typically, systems with a design flow over 5,000 gpd are required to get a discharge permit (although there are other systems that also require a permit pursuant to ARM 17.30.1022) if they are new or modified after May 1, 1998. Montana DEQ inspects the systems that are permitted by the state (Personal Communications, Eric Regensburger, June 12, 2006). City or county authorities issue all other permits.

2.2 County Regulations

Reviewing authorities can also adopt their own onsite wastewater treatment regulations. In the case of the Lake Helena watershed, Lewis and Clark County and Jefferson County both have regulations governing these systems. Per the state regulations (ARM 17.36.911(2)), local regulations may not be any less stringent than the regulations contained in ARM 17.36.3 and 17.36.9. However, variances may be granted by the local permitting entities as long as the variance does not result in a threat to human health or state waters (ARM 17.36.922 and 17.36.924). ARM 17.36.3 and 17.36.9 also gives counties and cities authority to develop more stringent regulations for onsite wastewater treatment selection, design, installation, and operation. The regulations for Lewis and Clark and Jefferson Counties are described in Sections 2.2.1 and 2.2.2, respectively.

2.2.1 Lewis and Clark County Regulations

Onsite wastewater treatment system regulations for Lewis and Clark County are defined in the report titled, "Onsite Wastewater Treatment Regulations," and are administered by the county Board of Health's Environmental Division (Lewis and Clark County, 2006). Similar to the state, Lewis and Clark County regulations prohibit contamination of state waters, and prohibit treatment systems from creating a human or animal heath hazard. Site design, preparation, and installation must also meet the regulations specified in the Montana DEQ Circular 4, ARM 17.36.9 (On-Site Subsurface Wastewater Treatment Systems), and ARM 17.36.3 (Subdivision Requirements).

Lewis and Clark County also has additional, more stringent regulations regarding the selection and placement of wastewater treatment systems. The following regulations apply only to Lewis and Clark County (adapted from Lewis and Clark County, 2006, Section 4.3):

- Mounds and sand filters or Level 2 treatment is required in those areas where:
    - Groundwater occurs at less than five and a half feet to ground surface as determined by groundwater observation during high groundwater season; and,
    - Analysis of soils by the Department or the Soil Conservation Service soils limitation ratings for septic tank absorption fields is severe.
- Pressure-dosed and sand-lined trenches or Level 2 treatment will be required in those areas where:
    - The depth to seasonally high ground water level is less than six feet from the bottom of the drain rock; and,
    - The percolation rate is faster than three minutes per inch.

- Level 2 treatment is defined as, "a SWTS that: (a) removes at least 60% of total nitrogen as measured from the raw sewage load to the system; or (b) discharges a total nitrogen effluent concentration of 24 mg/L or less."

As of October 15, 2005, only four systems were approved for Level 2 treatment – Recirculating Sand Filter; Orenco – AdvanTex; Fluidyne – Eliminite; International Wastewater Systems model 6000 sequencing batch reactor (MDEQ, 2005).

The Lewis and Clark County regulations (Sections 3 and 8) give the county authority to (1) issue permits for the construction or repair of wastewater treatment systems, (2) inspect systems to determine compliance with regulations, and (3) provide notice, require action, and issue penalties for failing systems. Before issuing a permit, a detailed site evaluation must be completed based on the county requirements. All other regulations governing the location, preparation, operation, or installation of wastewater treatment systems are similar to the state regulations summarized in Section 2.1 and described in MDEQ Circular 4.

2.2.2 Jefferson County Regulations

Onsite wastewater treatment system regulations for Jefferson County are defined in the report titled, "A Regulation Governing the Onsite Treatment of Wastewater in Jefferson County," and are administered by the county Board of Health (Jefferson County, 2006). Similar to the state, Jefferson County regulations prohibit contamination of state waters, and prohibit treatment systems from creating a human or animal heath hazard. Site design, preparation, and installation must also meet the regulations specified in the Montana DEQ Circular 4, ARM 17.36.9 (On-Site Subsurface Wastewater Treatment Systems), and ARM 17.36.3 (Subdivision Requirements). Overall, the Jefferson County regulations are similar to the State of Montana's (personal communications, Megan Bullock, June 13, 2006).

3.0 Conventional Wastewater Treatment Systems

Wastewater can be treated and dispersed to the environment through a variety of technologies that employ biological, physical, and chemical processes to digest, neutralize, or otherwise remove pollutants. Centralized wastewater facilities collect, transport, and treat sewage from dozens or hundreds of homes and businesses, while decentralized facilities provide similar services to individual or clustered buildings. Both types – centralized and decentralized – can discharge to surface waters or to the soil, but typically centralized facilities (i.e., conventional sewage treatment plants) will discharge treated effluent to a body of water, while decentralized systems discharge to soil absorption (infiltration) areas.

The Lake Helena watershed has a variety of systems from ranging from individual on-site treatment to large, centralized systems (i.e., Helena and East Helena treatment facilities). Nutrient removal varies with each system. The following sections summarize the various types of treatment systems and their nutrient removal efficiencies.

3.1 Conventional Onsite Systems

Individual onsite treatment systems consist of a septic tank and a subsurface soil absorption field. Buried in the ground, septic tanks are essentially watertight single or multiple chamber sedimentation and anaerobic digestion tanks. They are designed to receive and pretreat domestic wastewater, mediate peak flows, and keep settleable solids, oils, scum, and other floatable material out of the absorption field. Wastewater effluent is discharged from the tank and passes to the soil via a series of underground perforated pipes, perforated pipe wrapped in permeable synthetic materials, leaching chambers, pressure drip irrigation pipes or tubing, or other distribution system. From there, the partially treated effluent flows onto and through the developing biomat located at the soil infiltrative surface, and finally into the soil itself. Treatment occurs in the septic tank, on and within the biomat that forms at the soil infiltrative surface, in the soil, and continues as the effluent moves through the underlying soil toward groundwater or nearby surface waters.

Nitrogen in domestic wastewater can be removed through effective linking of aerobic and anaerobic biochemical transformation processes, but in general most conventional septic systems are not considered effective in removing nitrogen without additional treatment in the soil. Septic tanks remove 1 to 30 percent of the nitrogen in raw domestic wastewater (see Table 4). Percolation through 3 to 5 feet of soil can remove an additional 0 to 40 percent of the total nitrogen in septic tank effluent. Additional nitrogen removal is possible under optimum soil and denitrification (e.g., anaerobic and carbon-rich) conditions. Factors that favor denitrification in soil absorption fields include fine-grained soils such as silts and clays, layered soils that feature alternating fine-grained and coarse-grained layers, and organic matter or sulfur compounds in the infiltrative medium. Placing the soil absorption field high in the soil profile where organic matter is more likely to exist and dosing effluent to achieve alternating wet/dry (anaerobic/aerobic) cycles can aid denitrification and reduce nitrate leaching.

Most conventional septic systems are effective in removing phosphorus from effluent. Phosphorus precipitation can occur in the septic tank, and favorable phosphorus removal conditions (i.e., conditions favoring adsorption and precipitation reactions) exist for most soils of the United States. Combined, between 0 and 100 percent of phosphorus can be removed by a conventional treatment system (see Table 4). Phosphorus loading problems can occur in areas with older systems, highly permeable soils (e.g., sands), mineral-poor soils, nearby surface waters, and high system densities (USEPA, 2005).

Table 4. Nutrient concentrations and percent removal from conventional onsite treatment systems.

Type of System	% N Removal	N Concentration of the Effluent	% P Removal	P Concentration of the Effluent
Conventional Septic Tank	10-20% (USEPA, 2002) 28% (USEPA, 1993)	40 to 100 mg/L (Siegrist et al., 2000) 12-453, median 68 mg/L (McCray et al., 2005) 44.2 mg/L (USEPA, 2002)	57% (USEPA, 1993)	7.2–17.0 mg/L (Anderson et al., 1994.) 5-15 mg/L (Siegrist et al., 2000) 1.2-21.8, median 9 mg/L (McCray et al., 2005) 8.6 mg/L (USEPA, 2002)
Adsorption Trenches	10-20% (Siegrist et al., 2000)		0-100% (Siegrist et al., 2000)	0.01–3.80 mg/L (Anderson et al., 1994.)

3.2 Clustered and Centralized Systems

Cluster systems typically serve fewer than a hundred homes, but they can serve more. Under this approach, septic tank effluent from each home is collected and routed to another site for further treatment. Collection and movement of effluent to the final treatment site can be accomplished by gravity flow or pumps. The off-site treatment facility resembles a downsized centralized treatment plant, using similar technologies such as trickling (media) filters, aerobic lagoons, constructed wetlands, etc. Final dispersal of treated effluent is usually to the soil, due to greater treatment advantages and avoidance of NPDES permitting, monitoring, reporting, and other requirements.

Centralized wastewater service is characterized by 1) the system of piping which collects sewage at each home or facility and transports it to a central location, and 2) the central treatment facility, which typically discharges to a nearby body of water, but can discharge to the land (subsurface infiltration area, sprayfield) if conditions are favorable. Centralized systems generally consist of:

- Continuous flow, suspended growth aerobic treatment, usually in an open, aerated tank
- Fixed film treatment, with wastewater distributed over rock, gravel, sand, fabric, peat, plastic, or other media
- Sequencing batch reactors, sequential suspended growth treatment through an intermittent or continuous flow process
- Ponds, lagoons, and wetlands, which combine suspended and attached growth biological treatment with physical and other processes

Table 5 summarizes various types of cluster and centralized systems and typical nutrient treatment efficiencies.

Table 5. Nutrient concentrations and percent removal from clustered and centralized treatment systems.

Type of System	% N Removal	N Concentration of the Effluent	% P Removal	P Concentration of the Effluent
MLE Process – continuous flow, suspended growth process with an initial anoxic stage followed by an aerobic stage	~ 80	10 mg/L	~80-90	2 mg/L 1 mg/L with filtration
Four-Stage Process – continuous flow, suspended growth process with alternating anoxic/aerobic/anoxic/aerobic stages	~ 80-90	10 mg/L 6 mg/L with filtration	~80-90	2 mg/L 1 mg/L with filtration
Three Stage Process – continuous flow, suspended growth process with alternating aerobic/anoxic/aerobic stages	~ 80-90	10 mg/L 6 mg/L with filtration	~80-90	2 mg/L 1 mg/L with filtration
SBR Suspended Growth Process – batch process sequenced to simulate the four-stage process	~85	8 mg/L	~80-90	2 mg/L 1 mg/L with filtration
Intermittent Cycle Process – modified SBR process with continuous influent flow but batch, four stage, treatment process	~ 80-85	10 mg/L 8 mg/L with filtration	~80-90	2 mg/L 1 mg/L with filtration
MLE and Deep Bed Filtration Process – alternate 1 followed by attached growth denitrification filter	~ 90	6 mg/L – includes filtration	~ 90	1 mg/L – includes filtration
Submerged Biofilter Process – continuous flow or intermittent cycle process using one or more submerged media biofilters with sequential anoxic/aerobic stages	~75	12 mg/L	~80-90	2 mg/L 1 mg/L with filtration
RBC Process – continuous flow process using RBCs with sequential anoxic/aerobic stages	~ 75	12 mg/L	~80-90	2 mg/L 1 mg/L with filtration
Conventional Secondary Treatment – continuous flow activated sludge process (no enhanced nutrient removal; included for basis of comparison)	~ 50-60	20 – 25 mg/L	~ 30	7 mg/L

Adapted from Goess et al., 1998.

4.0 Alternative Wastewater Treatment Systems

Alternative or innovative systems such as mound systems, fixed-film contact units, wetlands, aerobic treatment units ("package plants"), low-pressure drip applications, and cluster systems are used in areas where conventional soil-based systems cannot provide adequate treatment of wastewater effluent. Areas that might not be suitable for conventional systems are those with nearby nutrient-sensitive waters, high densities of existing conventional systems, highly permeable or shallow soils, shallow water tables, large rocks or confining layers, and poorly drained soils.

Alternative or innovative systems feature components and processes designed to promote degradation and/or treatment of wastes through biological processes, oxidation/reduction reactions, filtration, evapotranspiration, and other processes. System summaries are shown in Table 6.

Table 6. Common alternative onsite treatment systems.

Type of System	% N Removal	N Concentration	% P Removal	P Concentration
Elevated/Mound Systems	44% (USEPA, 1993)	52.9 mg/L (calc[1])	10-90% (USEPA, 2002)	1-10 mg/L (USEPA, 2002)
Intermittent sand/media filters	15 to 35% (USEPA, 2002) 55% (USEPA, 1993)	42.5 mg/L (calc[1])	80% (USEPA, 1993)	~2 mg/L (USEPA, 2002)
Recirculating Sand/Gravel Filters	40-50% 64% (USEPA, 1993) 15-84% (California Regional Water Quality Control Board, 1997)	34 mg/L (calc[1]) 10-47 mg/L (California Regional Water Quality Control Board, 1997)	80% (USEPA, 1993)	~ 2 mg/L (USEPA, 2002)
Aerobic Treatment Units	24-61% (California Regional Water Quality Control Board, 1997)	37-60 mg/L (California Regional Water Quality Control Board, 1997)	30% (USEPA, 2002)	~ 7 mg/L (USEPA, 2002)
Constructed Wetlands	60%	20-35 mg/L	50% (USEPA, 2002)	~ 5 mg/L (USEPA, 2002)
Sequencing Batch Reactor	60% (Ayres Associates, 1998)	15.5 mg/L (Ayres Associates, 1998)	up to 80% (NEIWPCC, 2005)	~ 2 – 5 mg/L (NEIWPCC, 2005)
Nitrex	96% (Rich et al, 2003)	2.2 mg/L (Rich et al, 2003)	Up to 75% with modifications	~ 2 – 5 mg/L
Ruck System	29-54% (Brooks, 1996) (Gold et al, 1999)	18-53 mg/L (Brooks, 1996) (Gold et al, 1999)	~ 60-85%	~ 2-4 mg/L

[1] Calculated values: back-calculate raw load from McCray median and USEPA (1993) efficiency; then calculate resultant concentration for other systems using USEPA (1993) efficiency.

5.0 Treatment System Cost

Wastewater treatment cost varies widely based on the type of available and allowed systems. For individual onsite systems, installation costs for wastewater treatment can vary between $2,000 and $20,000 (see Table 7), and each system has additional associated maintenance costs. In comparison, costs for providing centralized sewer service for areas of new or existing development vary widely, depending on density of housing, pipe trenching conditions, the need for manholes and pumping stations, and capital costs for the construction or expansion of the central sewage treatment plant. It is generally less expensive to serve higher densities of housing (e.g., 2 to 6 homes per acre) because there are more connections per mile of sewer line. New treatment plant design and construction can cost $5,000 to $15,000 per house, with sewer line collection costs adding $10,000 to $20,000 or more per house for development on large lots (e.g., 3-5 acres). Homeowners then pay monthly rates for using the system. In the City of Helena, current sewer rates are $4.42 per month for the basic sewer service and $0.31 per hcf of water (City of Helena, 2006).

Monthly usage fees for centralized treatment are sometimes considered to be more accepted by the public, but most users know little about their wastewater treatment system and will pay regular operation/maintenance fees if they can avoid responsibility for large capital costs, such as a new septic tank or lateral line. Regarding other impacts, construction of the collection lines and the centralized treatment plant can cause localized sediment impacts, and operation of those lines over the long term can present challenges in terms of controlling inflow, infiltration, and leakage. Centralized treatment can also lead to unplanned development spurred by the need to recover capital costs required to build and operate centralized plants (Rocky Mountain Institute, 2004).

Table 7. Installation costs for onsite wastewater treatment systems.

Type of Onsite System	Installation Cost	% Cost Increase From Conventional Treatment
Conventional Septic Tank	$2,000-6,000 ($4,000 Average)	--
Adsorption Trenches	$4,000-$7,000	38%
Elevated/Mound Systems	$7,000-12,000	138%
Intermittent sand/media filters	$5,000-$10,000	88%
Recirculating sand/media filters	$8,000-$11,000	138%
Aerobic Treatment Units	$3,000-$6,000	13%
Constructed Wetlands	$10,000-$20,000	275%
Sequencing Batch Reactor	$8,500-$11,000	144%

6.0 Comparison of Systems

Centralized treatment is often viewed as providing more reliable and superior treatment, but upon closer examination both approaches – centralized and decentralized – offer excellent pollutant removal capabilities for the full range of pollutant parameters, at somewhat comparable costs (see Section 5.0). Table 8 compares the nitrogen and phosphorus treatment capabilities of the systems discussed in this report. In general, onsite systems with subsurface drainage are excellent at removing phosphorus, but not nitrogen. More advanced onsite systems or cluster systems can then improve nitrogen removal up to 75 percent. Centralized wastewater treatment facilities can achieve up to 90 percent reductions in both phosphorus and nitrogen with three and four stage processes. However, facilities with only primary or secondary treatment generally remove fewer nutrients than a conventional septic tank with an absorption field.

Overall, collection systems can be the most economical and effective method for treating wastewater. However, this assumes that there are (a) high housing densities, and (b) advanced wastewater treatment. Collection systems can be expensive and less effective than septic systems if these two conditions are not met.

Table 8. Comparison of treatment system cost and nutrient treatment.

Facility Type	Nitrogen Reduction Potential	Phosphorus Reduction Potential	Treatment Facility Cost Per House	Collection System Cost Per House	Avg. Yearly Wastewater Treatment Costs
Individual Septic System – Basic	Low	Moderate to High	$2,000 – 6,000	None	$25
Individual System – Mechanized (due to site constraints)	Low	Moderate to High	$6,000 – 8,000	None	$150
Individual System – Advanced Treatment	Moderate	Moderate to High	$7,000 – 10,000	None	$200
Individual System – Advanced N Removal	Moderate to High	Moderate to High	$13,000 – 16,000	None	$275
Cluster System – High Density – Basic Treatment	Low	Moderate to High	$5,500 – 7,000	$1,000 – 2,000	$300
Cluster System – Low Density – Basic Treatment	Low	Moderate to High	$5,500 – 7,000	$2,500 – 4,000	$350
Cluster System – High Density – Advanced Treatment	Moderate to High	Moderate to High	$8,500 – 10,500	$1,000 – 2,000	$400
Cluster System – Low Density – Advanced Treatment	Moderate to High	Moderate to High	$8,500 – 10,500	$2,500 – 4,000	$425
Centralized System – Conventional WWTP	Low to Moderate	Low to Moderate	$2,000 – 4,000	$5,000 – 15,000	$450
Centralized System – Advanced Treatment WWTP	Moderate to High	Moderate to High	$3,000 – 6,000	$5,000 – 15,000	$450

7.0 References

Bounds, T.R., " Design and Performance of Septic Tanks," Site Characterization and Design of Onsite Septic Systems ASTM STP 901, M.S. Bedinger, A.I. Johnson, and J.S. Fleming, Eds., American Society for Testing Materials, Philadelphia, 1997.

City of Helena. 2006. Wastewater Treatment [Online]. Available at http://www.ci.helena.mt.us/works/waste/virtual/treatmentplantupgrade.php (Accessed July 12, 2006).

Goess, G.W., Kenneth Williams, and George S. Garrett. 1998. Cost and Performance Evaluation of BNR Processes. Florida Water Resources Journal; December 1998. P. 11-16.

Jefferson County. 2002. A Regulation Governing the Onsite Treatment of Wastewater in Jefferson County. Jefferson County Montana Board of Health. Boulder, Montana.

Lewis and Clark County. 2006. The Regulations Governing the On-Site Treatment of Wastewater in Lewis and Clark County. Lewis and Clark County City-County Health Department – Environmental Division. Helena, Montana. Available online at http://www.co.lewis-clark.mt.us/health/environmental/index.php (Accessed June 8, 2006).

McCray, J.E., S. L. Kirkland, R. L. Siegrist, and G. D. Thyne. 2005. Model parameters for simulating fate and transport of on-site wastewater nutrients. *Ground Water*, 43: 628-639.

MDEQ. 2005. How to Perform a Nondegradation Analysis for Subsurface Wastewater Treatment Facilities. Montana Department of Environmental Quality – Permitting and Compliance Division. Helena, Montana. Available online at http://www.deq.state.mt.us/wqinfo/Nondeg/HowToNonDeReg.asp (Accessed June 13, 2006).

MDEQ. 2005. List of Subsurface Wastewater Treatment Systems (SWTS) that are Approved as a Nitrogen-Reducing System (Dated October 11, 2005). Montana Department of Environmental Quality – Permitting and Compliance Division. Helena, Montana. Available online at http://deq.mt.gov/wqinfo/Nondeg/level2_web_list.pdf (Accessed June 13, 2006).

New England Interstate Water Pollution Control Commission. 2005. Sequencing Batch Reactor Design and Operational Considerations. September, 2005. NEIWPCC, Lowell MA.

Rocky Mountain Institute. 2004. Valuing Decentralized Wastewater Technologies: A Catalog of Benefits, Costs, and Economic Analysis Techniques. Prepared by Rocky Mountain Institute For the U.S. Environmental Protection Agency. Snowmass, CO. November, 2004

Siegrist, R.L., E.J. Tyler, and P.D. Jenssen. 2000. Design and performance of onsite wastewater soil absorption systems. In Proceedings of the Decentralized Wastewater Management Research Needs Conference, Washington University, St. Louis, MO, May 19–20, 2000.

Stolt, Mark and Raymond Reneau. 1991. Potential for Contamination of Ground and Surface Waters from Onsite Surface Disposal Systems. Virginia Department of Health, Richmond, VA.

USEPA. 1993. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA 840-B-92-002. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

USEPA. 2002. Onsite Wastewater Treatment System Manual. EPA/625/R-00/008. U.S. Environmental Protection Agency, Office of Water, Washington, DC, and Office of Research and Development, Cincinnati, OH. February 2002

US EPA. 2005. Handbook for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems. U.S. Environmental Protection Agency, Office of Water, Washington, DC, and Office of Research and Development, Cincinnati, OH.

US EPA. 2005b. National management measures to control nonpoint source pollution from urban areas. Office of Wetlands, Oceans, and Watersheds; Nonpoint Source Control Branch. Washington DC.